BRITISH WELDING JOURNAL

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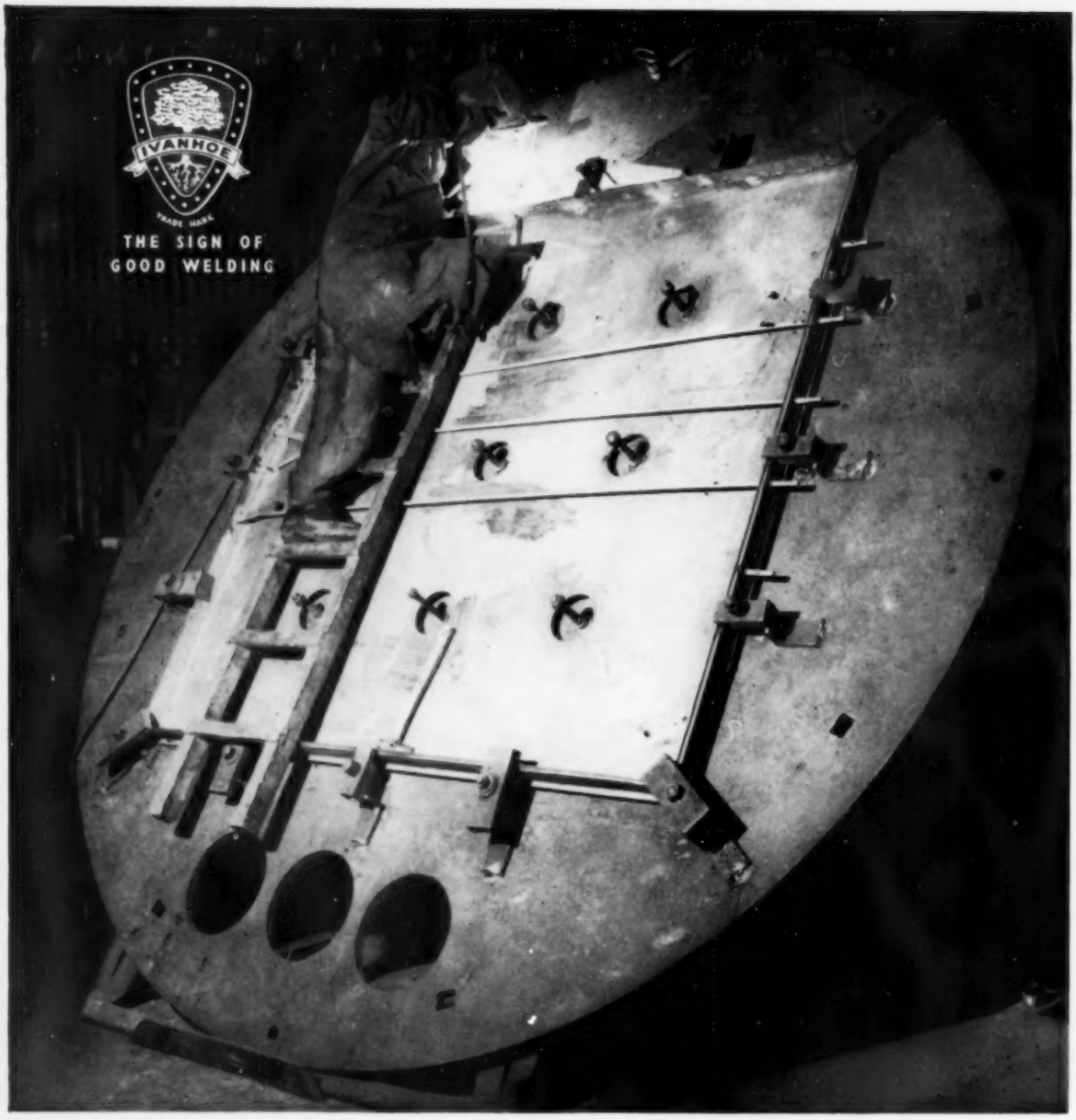

Jig welding a stainless steel jacketed tank bottom.

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$-T\left[\log_e\frac{1-x}{x}\right]_{x_b}$

This interesting looking formula by Borelius played some part in the development of one of the new alloy materials which made jet and turbo-jet engines possible. This alloy is known under the generic title NIMONIC belonging to the 80% nickel and 20% chrome type. To weld the NIMONIC cowlings of jet engines, Rockweld laboratories produced Chromac N. which is considered by engineers to be the best available electrode of its type. Chromac N. is recommended by Henry Wiggin & Co. Ltd. and approved by Rolls Royce Ltd. among many others.

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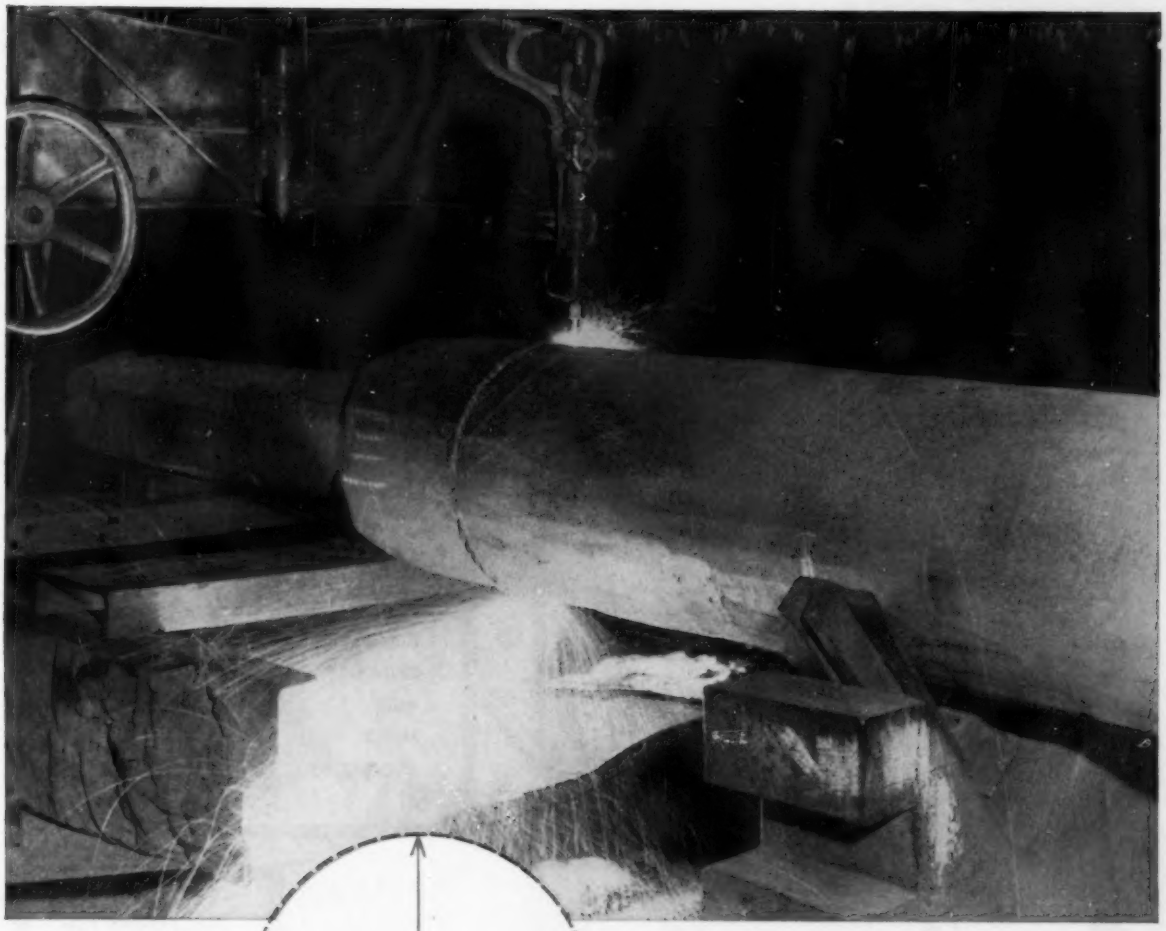

Cutting 22" steel with PYROGAS

This photograph was taken at the Dennystoun Forge, Dumbarton and shows machine cutting of a 22" diameter steel shaft. The fuel gas—Pyrogas, and the B.G.T. cutting nozzle were both supplied by Saturn Industrial Gases Limited.

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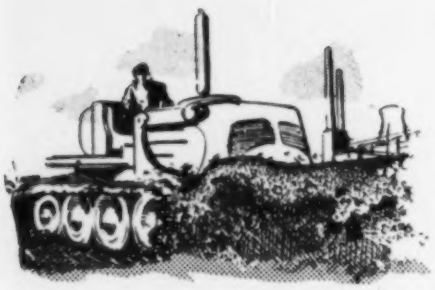

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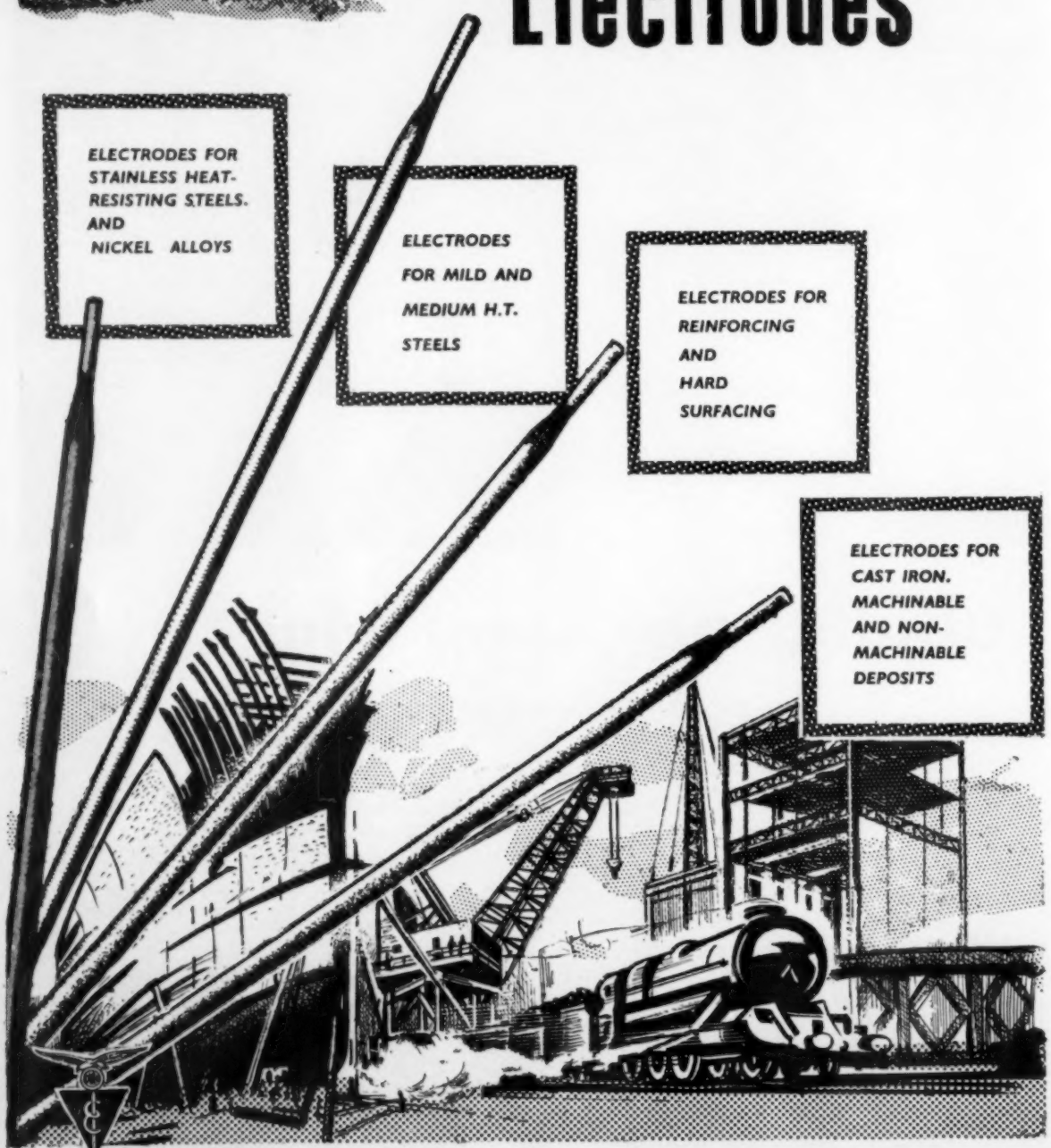

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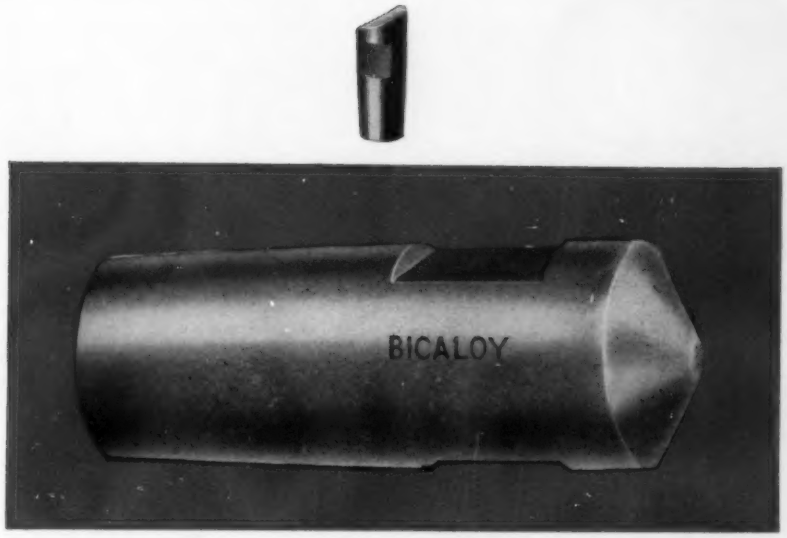

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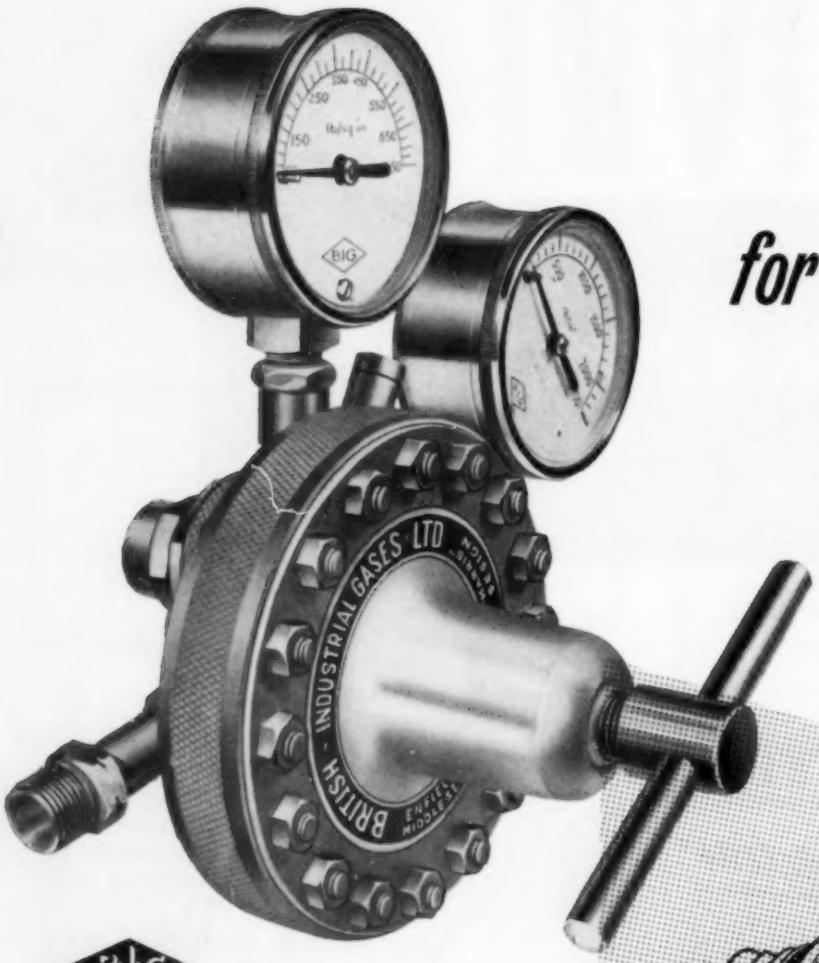

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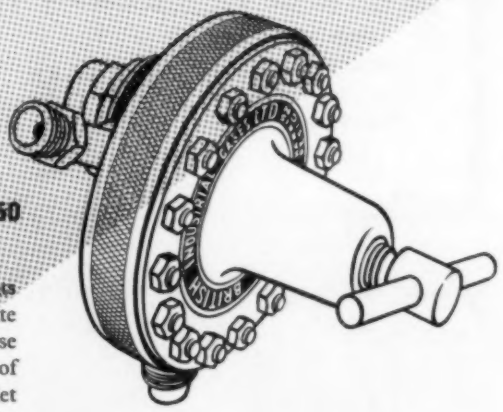

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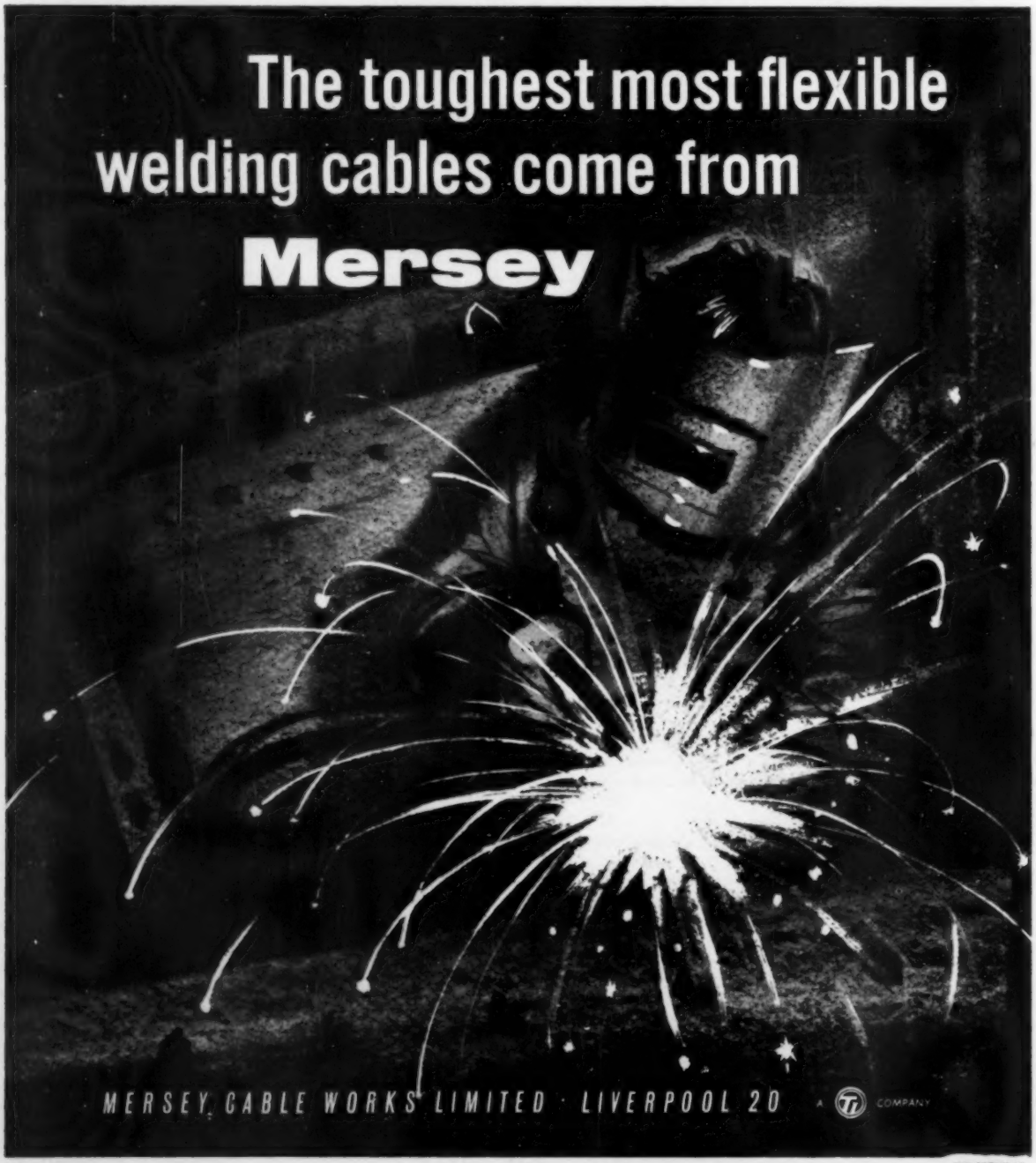

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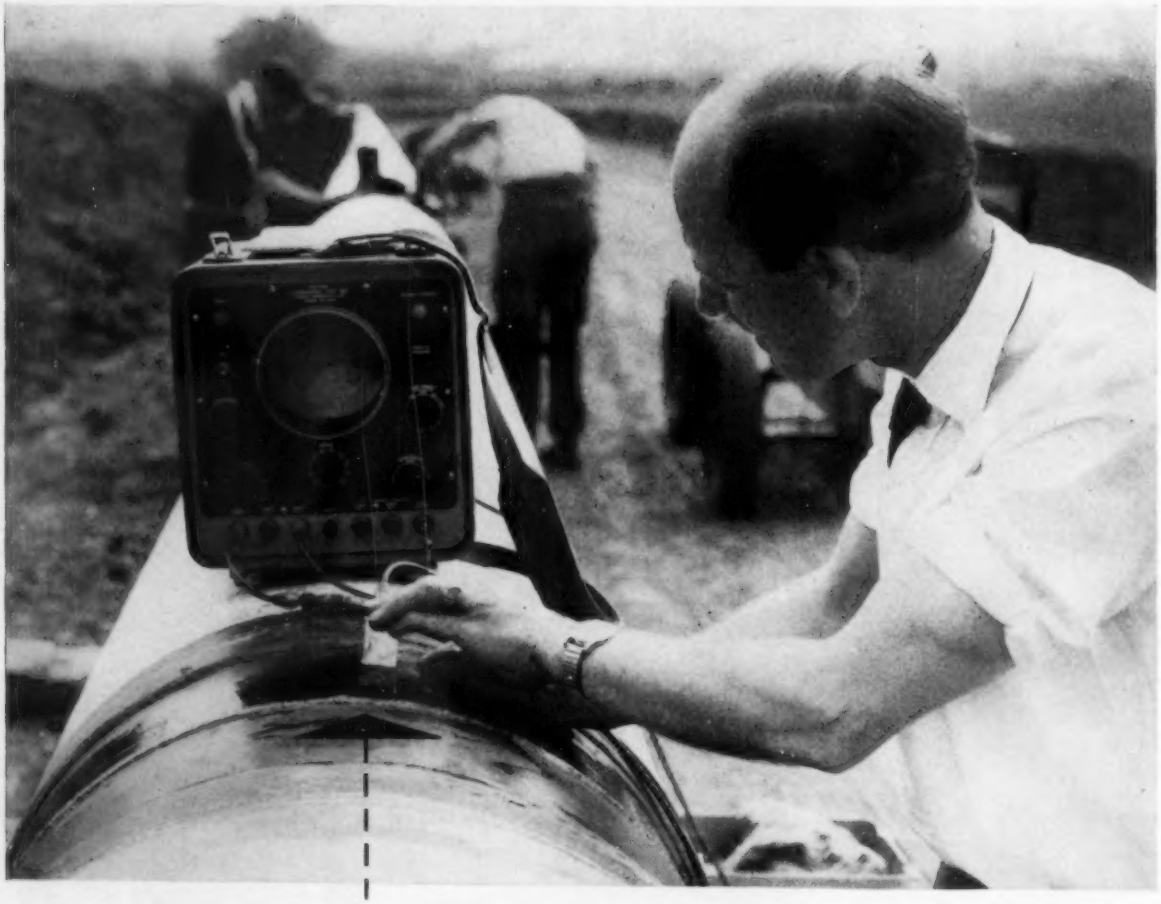

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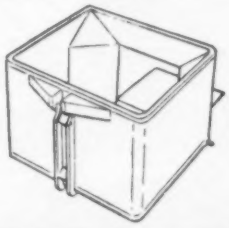
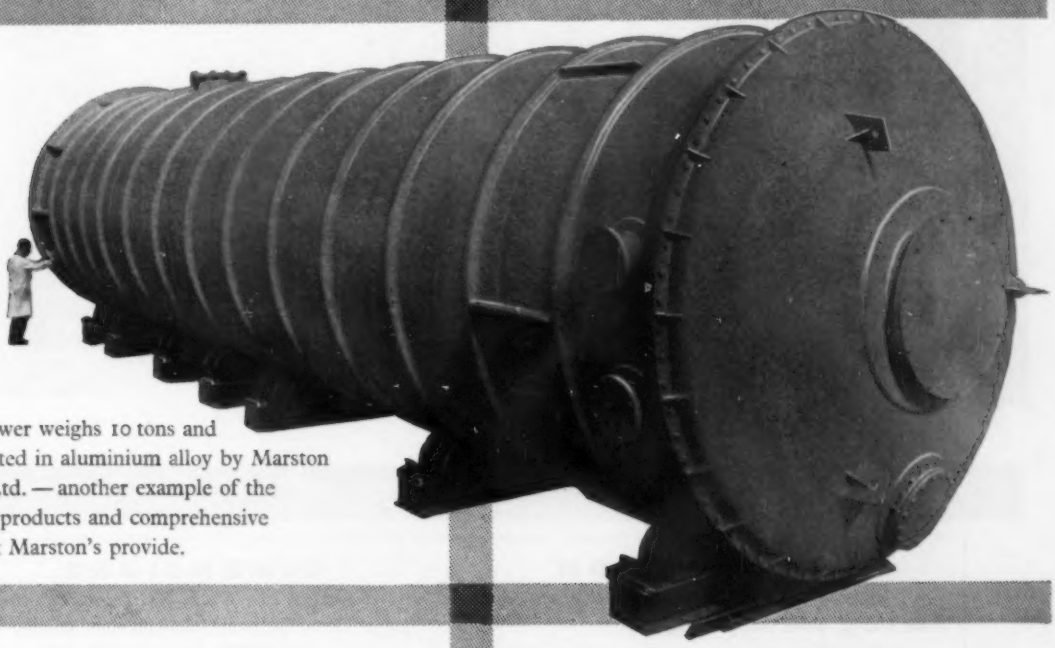
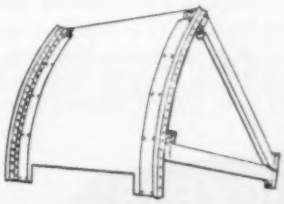


This truck-container is designed to carry granular material of particle size approximately $\frac{1}{16}$". Special attention had to be paid to the fit of the door and the smooth finish of the interior. The body ($\frac{3}{8}$" plate 'Kynal' M 39/2) was welded by the Argon arc and Argonaut processes.



This 52′ tower weighs 10 tons and was fabricated in aluminium alloy by Marston Excelsior Ltd. — another example of the specialised products and comprehensive service that Marston's provide.



This radial sluice-gate is 6′ 6″ wide and 6′ high. It is made of aluminium alloy, to minimise maintenance costs. To obtain a clean design free from any crevices where corrosion might start, the gate was welded by the Argon arc process. It is believed to be one of the first examples in this country of a radial sluice-gate in welded aluminium alloy.

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MAR 192

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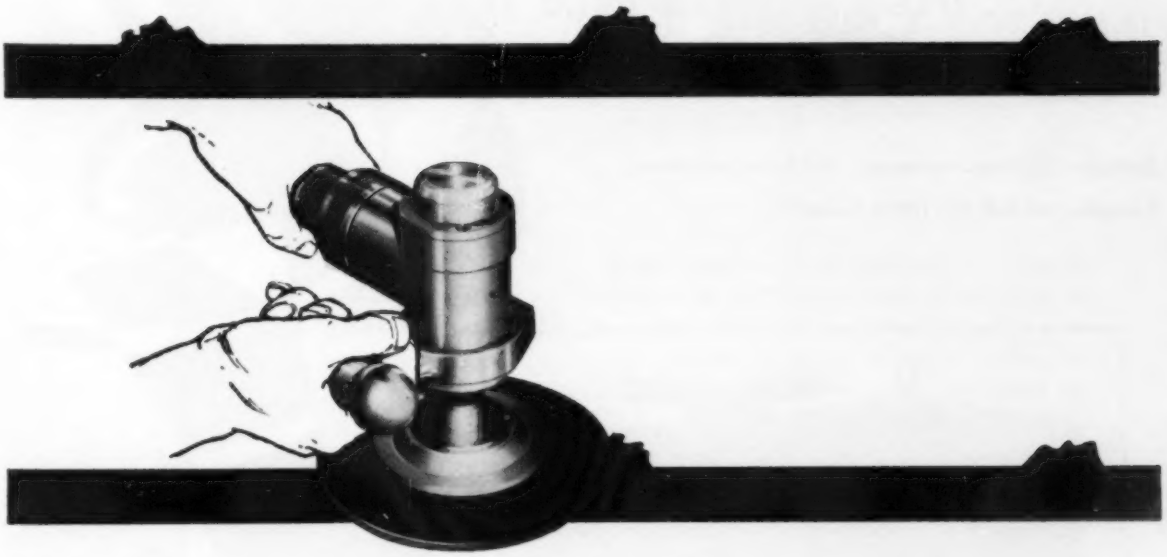

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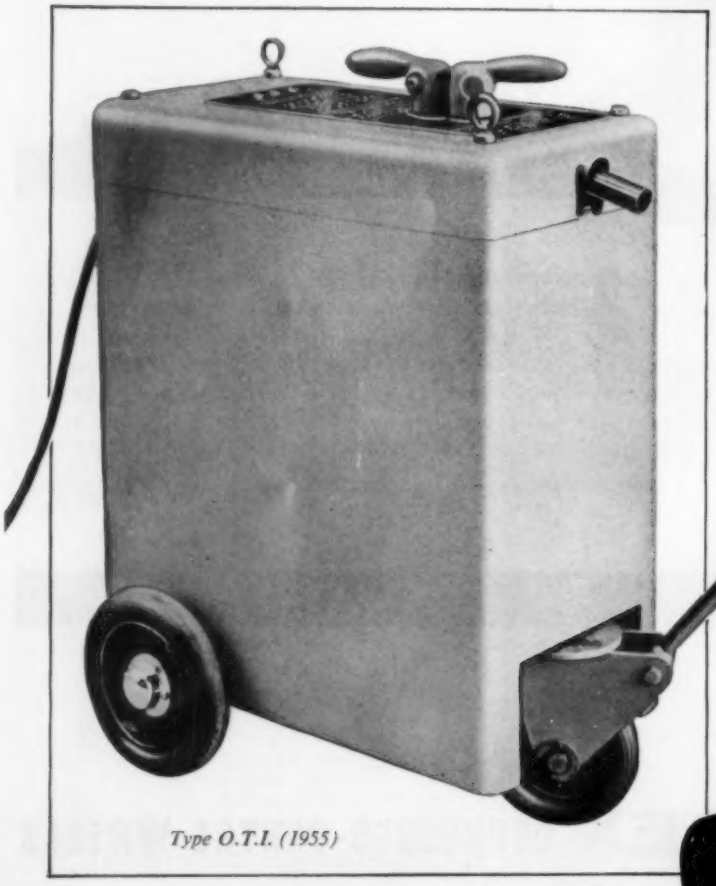

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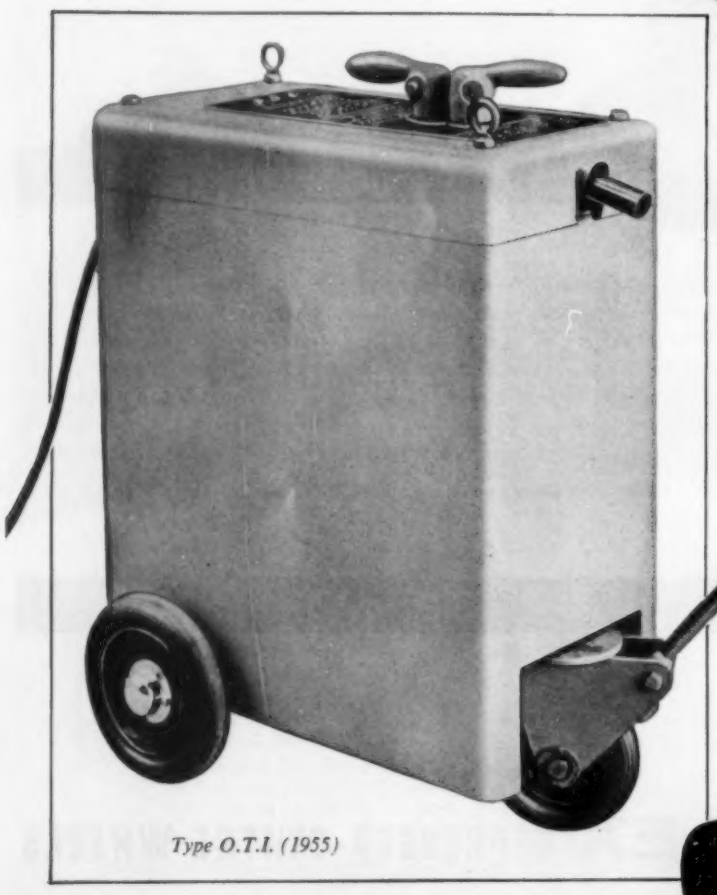

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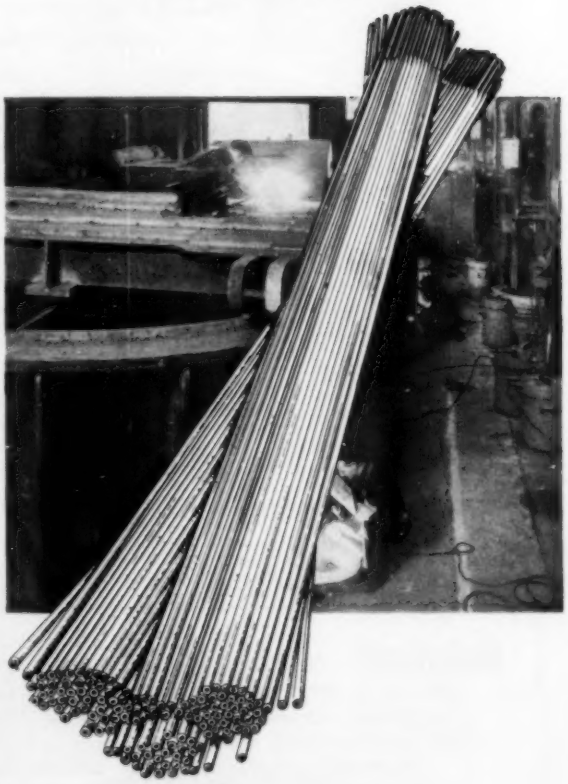

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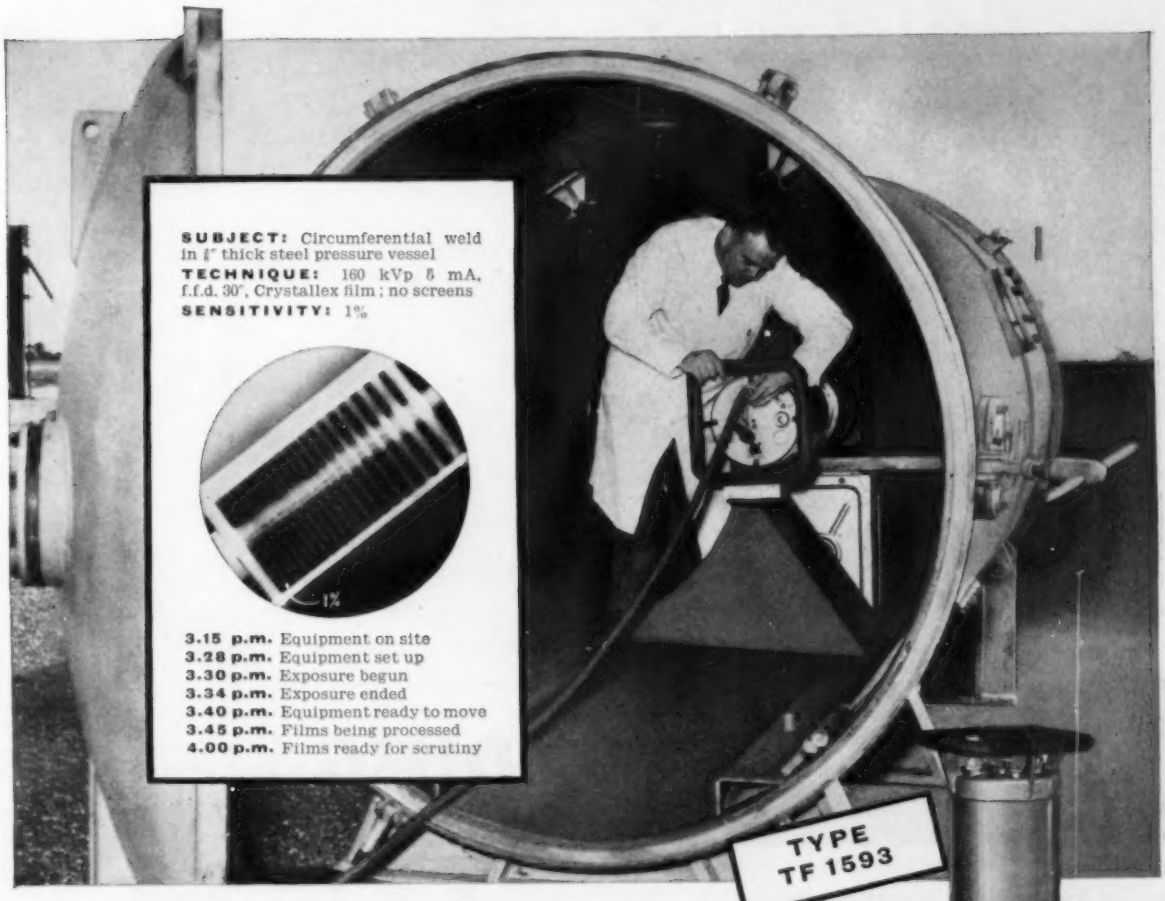
SUBJECT: Circumferential weld in ⅞" thick steel pressure vessel
TECHNIQUE: 160 kVp 5 mA, f.f.d. 30", Crystallex film ; no screens
SENSITIVITY: 1%
1%
3.15 p.m. Equipment on site
3.28 p.m. Equipment set up
3.30 p.m. Exposure begun
3.34 p.m. Exposure ended
3.40 p.m. Equipment ready to move
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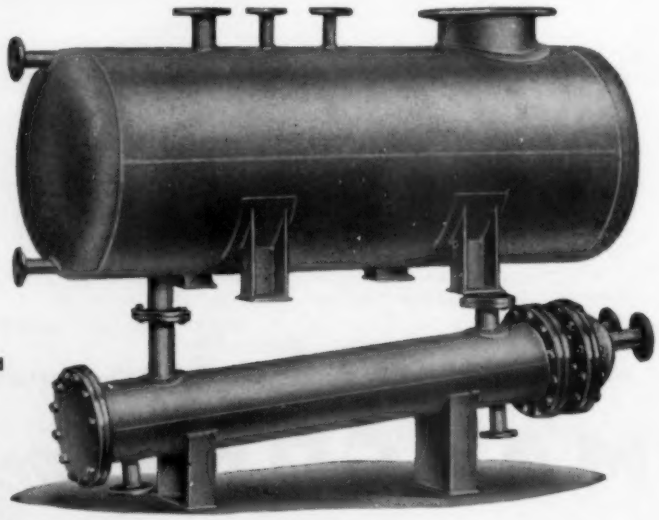

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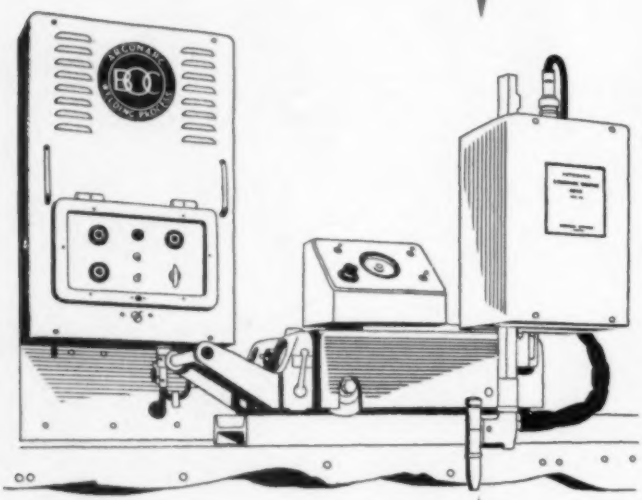

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54 Princes Gate, London, S.W.7
(Knightsbridge 8556)

Executive Editor:
C. ROWLAND HARMAN, B.Sc.(Eng.)
Editech
24 Smarts Heath, Woking, Surrey
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ANNUAL LECTURE 1958

The Influence of Welding on Structural Design

By Sir Alfred Pugsley, O.B.E., D.Sc. (Eng), F.R.S.

It is at once an honour and a pleasure to be invited to deliver this first Annual Lecture; an honour all the more sincerely felt because of my own inadequacy to do justice to the occasion, and a pleasure all the greater because of my personal regard for your President, Sir Charles Lillicrap.

I once had the duty of speaking about Sir Charles before Sir Winston Churchill and, remembering your President's great part in the welding of naval ships, jumped at the opportunity of quoting a famous directive of the last war. Sir Winston was concerned at the time about the vulnerability of our battleships to aerial attack—we all remember the tragic loss of the *Prince of Wales* off Malaya—and called for their decks "to be plastered with steel". Then, as now, I had before me our chief "steel plasterer"; but this time, I realize, I have before me a whole proliferation of plasterers.

In such company I must first explain that I have no qualifications as a welder—I can only talk to you tonight as an engineer who has perhaps seen something of the wood rather than the trees—an interested outsider. And I am encouraged to attempt this by a remark made by Dr. Paterson during your 1951 Symposium. In a discussion on the status and training of welding engineers, he argued that "in the present transitional age the emphasis must be on the engineer and not on the welder"; whether you agree with this or not, it is to me both an excuse and a comfort.

In the first two decades of this century, welding occupied in the engineering world roughly—I think this is scarcely an exaggeration—the position that iron nails did among carpenters a century ago. Welding was not then 'the thing' among structural engineers any more than the use of iron nails had been among the old carpenters. And I can remember, as a small boy having his iron hoop repaired, considering welding in just this light with the local blacksmith.

It was thus no great surprise to me, when I became a civil engineering student, to find that no reference to welding appeared in my text-books or in the lectures I attended. Structural Engineering books with any academic pretensions, even in 1920, just ignored the subject.

One wonders what occasioned this attitude to welding in its infancy. Here was a method of joining steel plating and structural sections with a promise of 100% efficiency in static strength and of absolute watertightness when required. One reason, no doubt, was the unreliable strength of joints made by the casual practitioner; there were no trained welders in those days, nor any systematic research to guide practice and training. Another adverse factor was the knowledge of the failures in Germany of welded steel bridges, some of which were believed to be associated with fatigue. Moreover, there was not enough satisfactory experience of welding to point to some of its less obvious merits, such as its value as a means of producing structural continuity and of securing fixity in joints. As can easily happen with fresh engineering developments, ill-judged applications of welding guided by inadequate evidence as to its real properties set back rather than forward its general advancement.

If we turn for a moment to the present day, we see a very different picture. Thirty to forty years, with a major war included, have brought welding into structures of nearly every kind. It has brought such changes into shipbuilding that the difficulty now is not to find skilled welders, but to find any trained riveters at all. Again, welding has become an essential feature of most steel containers and pressure vessels for fluids, whether large or small, especially in the gas and oil industries. Moreover, its use has spread outside the field of static structures to moving vehicles and to parts of machinery. And in the course of this welding revolution, your own Institute has naturally enough come into being.

As a technique, welding thus now ranges so widely that it is impossible to consider comprehensively every facet of its influence upon the structures to which it has been applied; or indeed to appreciate fully its effects in a more limited way, as upon the theory of design. In seeking to discuss the influence of welding upon

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This, the first of the Annual Lectures, was delivered at a special meeting of the Institute, held at 54 Princes Gate on Wednesday, 12th March, 1958.

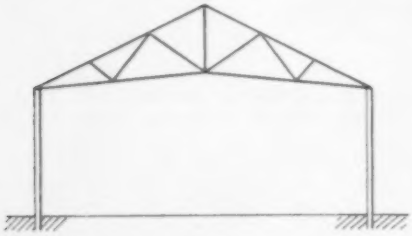
Sir Alfred Pugsley, Professor of Civil Engineering in the University of Bristol, is President of the Institution of Structural Engineers.

structural design, therefore, I can hope only to deal with some aspects of the matter, and those the ones best known to me.

Single-storey shed design

One of the most powerful ways in which the development of any new material or new method of jointing can affect structural design is through its influence on structural theory, whether direct or indirect. Any advancement or extension of theory, particularly of a kind and form amenable to practical use, has at once a range of influence in and beyond the original field of application; and, moreover, a period of influence in time in and beyond even that of the useful life of the new technique itself. It is natural, therefore, and profitable also, to look first at some examples illustrating the influence of welding on design through its influence upon the general body of theoretical knowledge about structures.

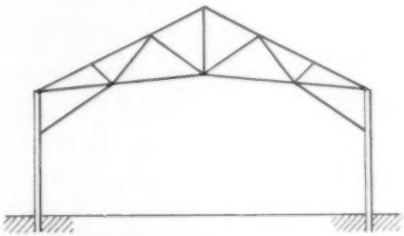
A classic example of the interplay of theory and practice in structures is to be seen in the development of the single storey industrial shed. This started, in its relevant form, in the middle of the nineteenth century, when the construction of such sheds became based upon a structural skeleton comprising pairs of cast iron columns spanned by wrought iron roof trusses, clothed first with brick walling and slates, and later with galvanized corrugated iron. The essential element in these structures consisted of two columns with fixed bases crowned by a framed roof truss resting upon



them. Wind loads were seldom specially provided for, and any attempt to fix the shoes of the roof trusses to the tops of the columns in such a way that bending couples, as well as vertical loads, might be transmitted to the columns, was avoided. The weakness of cast iron in tension, and to that extent in bending, was of course already well known.

When mild steel replaced both cast iron and wrought iron in this kind of structure, no change was at first made in its general design. Indeed, it was not until my own student days that a lively interest in wind loads on sheds and, as a result, in the secure fixing of the trusses to the columns, as by 'knee-bracing' members, arose. Thus the first edition of Morley's text-book on the theory of structures,[1] published in 1912, has only a very short section on knee-braced frames; but by 1920 roof trusses with knee-bracing members were of wider appeal. An early and, at the time, well-known book on the design of steel-framed buildings, restricted mainly to single-storey ones, by E. G. Beck,[2] published in 1920, has several chapters on the matter. Thus in the course of the first two decades of this century, mild steel had come to provide the skeleton of the shed, the bolted joints of the wrought iron truss had been replaced by riveted joints throughout, and a scheme for making truss and columns into a single structural unit had developed.

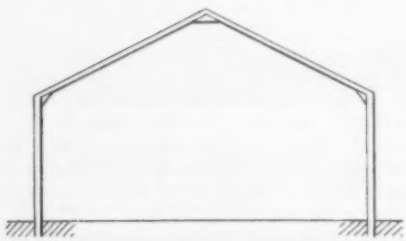
But the knee-bracing scheme did not become generally popular in Britain. It encroached on the shed



interior space and it required a type of elastic analysis beyond the capabilities of the ordinary designing draughtsman of the time. Wind loads could be dealt with otherwise—as by horizontal bracing between trusses in the plane of their lower tie members and vertical bracing in selected bays in the planes of the wall columns. As a result, the overall effect of the introduction of mild steel and riveting into shed construction was to settle once again upon a structural unit of two columns with a truss resting upon them; but this time more thoroughly braced for wind loads.

Thus the matter stood, apart from a few experiments, even in 1940. But most of these experiments involved welding, which was first introduced into sizable engineering structures in the late 1920's and early 1930's, mainly in Germany and America. One way, and a natural way, to introduce welding into our shed structure was merely to try to replace the riveted joints by welded ones. Out of this approach has come the modern truss frame of light tubular members welded together in as direct a fashion as possible at the "joints", and resting upon, and sometimes knee-braced to, tubular or other steel columns. But this development, important though it is, has brought with it no new extension of theory likely to have widespread influence.

Much more influential has been the attempt to construct sheds of unbraced portals consisting of members made continuous by direct welding and designed



to carry lateral wind loads by shear and bending actions in their own planes. The elastic theory of such portal frames, whether with horizontal cross-members

or beams or with continuous pitched rafters, had already been developed, particularly in the 1920's. But before the general acceptance of welding, hesitation about the stiffness of riveted joints, if used in such structures, and doubts as to any economy resulting from the replacement of a truss (with members loaded endwise) by an unbraced frame (with its members in bending) limited its applications in practice.

It was, strangely enough, the economy issue, brought to a head by the last war, that gave the unbraced welded frame its real chance. Just before and during the 1940's, Professor J. F. Baker and others, realizing the limitations inherent in the design of such portal frames by elastic analysis, and realizing also that welding would ultimately provide the continuity that riveting could not certainly produce, started to study the ultimate strength of such frames under vertical and horizontal loads. Out of this work, and somewhat similar work in America, has grown the plastic method of design;[3] and, so far as steel building structures are concerned, the modern interest in ultimate strength as well as in elastic behaviour.

Thus, in this instance, the development of welding has not only led to the advancement of a particular type of structure, but it has also helped greatly to found a method of design of wide application in structural steelwork.

There is another feature of this first example that is common to many such. As soon as a new method of joining structural components arises (welding is, of course, not the only one, even at the present time) and engineers gain experience and confidence in its use in conventional situations, then by proceeding to develop their structures to take full advantage of the new method, they in turn produce new joint and welding problems. The portal is an example; it was early found by test that the simple butt joint between the members meeting at a corner, whether square or at some angle, was inadequate to meet the bending moments to be transmitted. This was not so much because of any welding failure, but because new local stress concentration and stability problems arose that were outside previous structural experience. Types of welded joint had therefore to be elaborated in the more heavily loaded examples; and these in turn required for their design further extensions of structural theory. Another cycle was thus begun. This process has, of course, shown itself most in the development of standard types of welded joint for the frames of multi-storey steel buildings—types of joint designed to permit of good welding, to provide adequate strength and to facilitate fabrication and erection.

Elastically restrained struts

Let us turn from this building example to a humbler one in another field. Those of us who are old enough to have been interested in electric tramway lines will have seen, particularly in the early days of their development, how, on a hot summer's day, parts of the line would sometimes lift in long waves out of the roadway, carrying granite sets or wood blocks with them. The rails were butt welded, partly for electric continuity, and, in spite of the way they were fixed down, the longitudinal compression induced by thermal expansion on an unusually hot day could produce this severe upward buckling. These events were at the time in the experience of most schoolboys and were used by their physics masters as a good illustration of the reality and power of thermal expansion in metals.

But why did rails buckle in wave form and upwards rather than sideways, and why was the observed wave length so regular? As is now well known, the answers to these questions were found by the analysis of the behaviour of a long strut in an elastic medium.[4] It was realized that, due to the compression induced in a continuous rail by a rise of temperature, the rail became a strut—a long slender one—restrained against vertical and lateral movement by the road materials. This restraint was idealized, for theoretical treatment, by imagining the strut to be stayed elastically along its length.

It was found that for a strut under such conditions there was a critical load rather like the Euler load for a simple pin-ended strut, and that this was independent of the overall length of the rail. If this critical load were exceeded, then the strut would buckle in a sinusoidal wave form with a wave length that was settled by the ratio of the bending stiffness of the strut itself to the stiffness of the elastic restraining medium. The stiffer the restraint, the shorter would be the critical wave length and the higher the critical load.

Why, you may think, should I mention this trivial example of the influence of welding? Admittedly, we are today returning to the same problems with the long welded lengths of railway line now being developed, and we are using the same theory, in developed form, to ensure the practical suppression of the old buckling trouble; but is this reason enough to quote a simple butt welding example?

For those of you interested in modern developments of structural theory in the field of buckling, reasons will, of course, readily come to mind. But they are nevertheless more worthy of mention than one might at first sight suppose. The theory of a strut in an elastic medium is itself capable of wide application, qualitatively if not quantitatively. Piles in foundation structures are columns more or less supported by the surrounding soil, steel reinforcing rods in concrete, when in compression, are stayed against buckling by the concrete surrounding them, and the thin outer plates of sandwich construction as used in aeronautics are stabilized by the elastic filler between. Less directly, the theory is the key to the many structural stability problems that exhibit natural wave-lengths in buckling, unrelated to end conditions. Examples are the natural wave lengths of the local buckles that can occur in thin-flanged beams and struts in compression, and the tension-field waves in the thin webs of plate girders in shear. Indeed, the production of this early theory was a most valuable step in the understanding of buckling problems and consequently is still an excellent educational exercise. A small early effect of using welding has thus contributed to a wide variety of structural problems.

Plate girder design

This theory of a strut in an elastic medium can be used to discuss approximately the problem of stabilizing the compression boom of a bridge truss or the

compression flange of a plate girder. An early form of the theory was in fact devised and so used in Russia towards the end of last century.[5] A number of through bridges with deep trusses had collapsed; their compression booms were unbraced laterally in any way. The stability of the booms was examined by treating each as a strut with a compression load gradually increasing from its ends to its centre and elastically restrained against lateral movement by the stiffness of the truss web members, acting in bending like cantilevers fixed at the bridge floor.

Such accidents provide early large-scale examples of lateral instability in beams but, of course, the problem had arisen much earlier in the traditional use of deep narrow timber joists for floors. For large spans, it was long customary in such floors to stay the joists against lateral or torsional movement by fitting 'herring-bone' strutting between the joists at intervals along their span; this was an early form of lateral stabilization still in use among carpenters.

What has this problem of lateral instability to do with welding? I think the immediate answer lies in some current developments in welded girder construction. The typical riveted plate girder bridge of the first half of this century provides, when of the through type, the modern parallel to the old 'open' truss bridge. It was seldom deep enough to permit of lateral bracing between the compression flanges and was therefore stayed laterally only by 'fixing' near the lower flange to the deck structure. We appear now to be entering a new era in the use of plate and box girders, facilitated by the use of welding in place of riveting. One very noticeable feature of the new plate girders is the disappearance of angle sections in their construction, first in the make-up of their flanges and now in the web stiffening members. Another aspect of the current situation is the tendency to use plate-girders for longer spans than hitherto usual, resulting in girders of deeper and deeper section, and in the introduction of horizontal web stiffeners as well as vertical ones.

Let us look at the compression flange stability problems in this new context. In the older riveted designs, it was for long a custom to adopt heavy flange angles, and these provided a substantial proportion of the total flange area. Now these angles have disappeared and all the flange area is in one heavy plate welded directly to the web plate. By keeping this one plate of much the same breadth as in the older designs, it will be realized that, for a given flange area, the moment of inertia of the flange section relevant to lateral flexure will be rather greater in the new than the old design. Bur the torsional stiffness of the girder as a whole—at least when used in isolation—plays some part in its resistance to lateral instability and this, as in an **I**-section, depends appreciably on the volume of material at the junctions of web and flanges. Whatever the detailed action in this way of the flange angles in the old designs—and there is little experimental evidence available—we may have lost a little in torsional stiffness by adopting the new design of flange.

But this is a minor detail compared with two other factors, neither of which operated appreciably, if at all, in the old designs. Local instability of the flange plates, due to compression, in the riveted case arose for consideration in practice only as a point to be watched in settling the rivet pitch for joining the cover plates to the flange angles, and in deciding upon how far the cover plates could safely project laterally beyond the flange angles. But now this question of local instability—the tendency for a flange plate to buckle, elastically or plastically, in waves along its free edges—is vital to the design of the whole flange; its consideration is an essential step in deciding upon the width of the flange in relation to its thickness.

Let us look a little closer at this first of our new problems, or rather at this new emphasis on an old problem. The modern flange can, of course, be better stabilized at intervals along its length by the vertical web stiffeners, which can now be securely welded at their ends to the underside of the compression flange plate. But the wave-length of the local buckling liable to arise along the flange plate is of the order of the plate width, whereas the spacing of the web stiffeners has been of the order of the web depth. Thus, to have much effect on the critical compression stress for local buckling of the flange, the web stiffeners would have to be spaced at a pitch equal to or less than the plate width; this would clearly be uneconomical. One is led, therefore, to the use of flange plates thick enough to prevent local buckling on their own account, with reliance on the thinner web plate and its stiffeners to prescribe the vertical position of its mid-point.

But we cannot leave the matter here; what about the problem of the lateral stability of the girder as a whole? Must we not now pay more attention to the interaction of local and lateral stability, to the possible occurrence of a combined instability involving both local waving of the compression flange and its general lateral displacement, the one perhaps precipitating the other?

This, I surmise, is a problem of the future and on which by chance, as a matter of the pure curiosity wisely allowed to academic folk, I think some work done at Bristol will have a useful bearing. There, back in the years 1952–55, S. Cherry[6] in my department investigated this interaction problem, mainly in the elastic range, both experimentally and theoretically. It was thought then that his work, in which aluminium alloy models were mainly used, might bear on design in the long-term future; the time for its reappraisal and use now seems closer. At present available only in thesis form, its more interesting results must be more generally published as soon as possible.

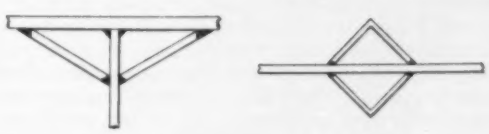
I mentioned earlier that there were two new factors involved in welded plate girder design, but I have so far only commented on one. The second arises in a way hitherto more familiar to aeroplane designers than to plate girder designers. Back in 1927, H. Wagner,[7] working on the development of metal construction for aeroplanes, theretofore largely built of timber spars and struts with wire bracing members, realized that the web of a metal plate girder, if provided with suitable vertical members at intervals, could be allowed to buckle without causing failure of the girder as a whole. He thus came to build up the theory of the tension-field web, in which the web plate was able to carry, by diagonal tension, shear forces many times its critical buckling load. To achieve this

it was essential that the girder flanges were held securely apart by the vertical web members and that each flange was itself capable of withstanding, as a beam spanning between these web members, the severe inward pull of the buckled web. With this type of web action clearly in mind, aeroplane designers pitched their web verticals or 'stiffeners' closer than the depth of the girder and used heavy angles or special deep extruded sections for their spar flanges.

But now what are we doing about the thin flange plates of our welded plate girders? To achieve web economy, in Britain and also in Germany and the U.S.A., we are seeking to imitate the aeroplane spar by allowing the web plate to buckle elastically, if not into real tension fields, at least to the extent of permitting the shear force to exceed the critical buckling load by some 50%. But if this is done, any inward pull from the web upon the flange plate, already highly stressed in compression, finds itself acting upon a thin flange member vulnerable to this form of vertical loading. Some of Dr. Rockey's recent experimental work[8] at Swansea, designed primarily to discuss the better stiffening of web plates, has incidentally produced examples of the failure of flange plates by local vertical collapse. It is not certain that the inward pull of the web plate played a large part in these failures, but they clearly point to the type of flange plate collapse that could be precipitated by such inward pulls between vertical web members.

We have looked now at three apparently very different design problems associated with the introduction of welding into structures over the past fifty years or so. An early tramway line problem now springing to new life on our main railway tracks, a classical case represented by the gradual development of frame design for single-storey sheds, and the more complex case of plate girder design still under development. All are problems in which welding has played a part and all are ones which, stage by stage, have contributed substantially to the body of structural theory. One was linked with the development of the theory of strut stability when stabilized by surrounding elastic supports, another with the development of the plastic theory of structures, and the last with the widening horizon of elastic stability theory when more than one mode of deformation is involved. All are thus examples of the way in which welding can have, and has had, both short and long term effects upon structural design.

To point this influence in current fashion, let us look once more at our last problem, that of designing efficient welded plate girders of large size. Dr. Rockey, in his recent paper, has pointed to possibly improved forms of web stiffeners; the verticals, for example, would permit of higher shear forces being carried by a given web plate without undue deformation if they each had, in themselves, high torsional stiffness. In this sense, the move from angle-section stiffeners to simple plate stiffeners, as was natural with the introduction of welding, has been a little retrograde; it might be much better, with welding, to use equal angle sections toe welded to the web plate so as to form triangular tubes, perhaps one on each side of the web for symmetry. It does not take long, thinking on these lines, to wonder whether our present flat plate compression flanges would not be better replaced with double triangular sections built up by three flat plates, one across the web top and the other two suitably



inclined down from the edges of the top plate to either side of the web; or a rectangular box flange may have merits. In any such closed section, as is well known among aeroplane designers, even elastic buckling does not necessarily precipitate total failure; the hard 'corners' remain capable of carrying further load. All this is not really new; Brunel developed his famous tubular flanges with good reason. But it shows how welding may infuse new life into plate girder design.

Welding in shipbuilding and transport

I have so far made no technical comment on what, I suppose, is the greatest field of application and achievement in welding to date, and in your presence, Mr. President, I hesitate to do so. For as a leader in the use of welding in ships' structures you will know much more about the matter than I can hope to do. I am not, therefore, going to attempt to assess this great development of welding, but rather to take a few of its apparently incidental effects and point to their wider importance for structures in general.

When I first became interested in the application of modern theory of structures to the study of ships' hulls, I was impressed with the apparent relevance of shear lag or diffusion theory to such structures. This is the theory of the diffusion of stress from a concentrated load or member into a plate structure, or vice versa. Aeronautical engineers were largely responsible for the development of this theory, and naval architects had as yet shown little interest in the matter. It needed the widespread introduction of welding, with the concomitant possibilities of both stress diffusion and stress concentration, to create a lively interest in the shipping world in shear lag theory. In the hands first of H. L. Cox and later of Caldwell[9] and others, it has since been applied to a variety of ship problems, particularly those associated with the development of superstructures capable of making a substantial contribution to the structural strength of a ship. In some important conditions of loading, a ship is essentially a deep beam of shell-like construction. This is itself a difficult structure to analyse accurately, but with a superstructure added it becomes a beam of irregular section, whose approximate analysis presents considerable difficulty. Shear lag theory, devised originally for some local strength problems in aeroplanes, has here proved its worth and become a tool capable of application in shell structures generally; and both because of the freedom of form made possible by welding and of current trends in structural design for other reasons, of such shell-like monocoque structures I am sure there will be many in future.

One such structure, again in the vehicular or moving class, has already arrived in the form of railway and road coach bodies. Here, the introduction of welded

plate construction has so far followed the general lines of earlier riveted construction, but with car bodies much of the old base frame has disappeared, and pressing and welding techniques have produced what is virtually a new type of car structure. But anyone who has inspected such a car after a crash, or has thought about the reasons for his increased car insurance, will know that there are real problems remaining about the behaviour of such structures under impact conditions. For car and coach bodies of all kinds, we have still to learn how best to arrange the structure so as to absorb kinetic energy on impact with an economical localization of the damage and yet without imposing undue decelerations on the passengers. Considerable research work on these problems is now in hand both in the U.S.A. and in Britain; some is being done at Bristol. It is hoped that as a result better and safer coach and car body structures will arise; in any event, I am sure much new fundamental information will appear that will have widespread application.

Behaviour of metals under stress

It is not only in the field of structures proper that the introduction of welding has led to the advancement of knowledge. With the development of continuous shell-like structures, such as ships' hulls and oil and gas holders, have come fundamental advances in the understanding of metals under stress. Spectacular failures by sudden cracking have brought disasters, but out of our mistakes we have already learnt much. The failures of the *Comet* pressure cabins led to an intensification of work already started by the earlier welded ship failures, and as a result brittle fracture, fatigue and the study of residual stresses are all being linked in a developing theory of cracks in metals, with great potential for the future.

From the shipping side came the beginnings of an understanding of the association of crack formation with the accumulation of elastic strain energy (in residual stress form) and with the physical reasons for the transition between brittle and ductile fracture in metals. From the aeronautical side came, likewise, extensions of fatigue knowledge in regard to slow and rapid crack growth. And the two are now being linked to provide a basis, on an engineering scale, for a new appreciation of both brittle fracture and fatigue in plate structures. Contrariwise, this information is having, and will continue to have, its influence on the selection and provision of materials for structural use less liable to fracture and fatigue troubles than those in general use in the past.

Architectural style and structural possibilities

Straub,[10] a well-known continental historian of civil engineering, has pointed to a structural trend that has developed over the past century. It is represented by the gradual development, as he believes, of a "technical style" in architecture. At its best it has many merits, but at its lowest it is associated with the slavish adoption of forms of construction that are conveniently amenable to structural analysis. This is characterized by a tendency to adopt simple beams instead of statically indeterminate arches; to adopt flat roofs of beams and slabs rather than domes.

Such a debased technical style is all too easy, especially at a time when architects are often lacking in an understanding of the technical achievements and possibilities of their day. Much now depends on their collaboration with structural engineers, and upon the willingness of the latter to exploit their skill. I think we are today at the gates of a new era in construction; the new freedoms being introduced by the welding of steel, for example, by the growth of mechanical handling equipment, and by the continuing development of reinforced concrete, are creating new opportunities for structural engineers and architects alike. Let us cease to cling automatically to easily analysed structures and return more often to building the structures we like and want, whether we can, at this moment, analyse them or not. Bridge trusses and arches and domes were built, and usually successfully, long before satisfactory theories of their behaviour under load were devised. Model and full scale experiments were often behind these ventures and can surely, with our greater knowledge, be even more fruitful today. Just as the engineers of the early nineteenth century were tempted into new ventures by the new materials and techniques of their time, so we must allow ourselves to be tempted into the new ways suggested by our needs and facilities. In this process I hope welding will take its part and continue to tempt us into new ventures or to find new answers to old problems. When troubles come, as they have and will, let us remember the successful struggles of our predecessors and not only overcome our failures but rather make them stepping stones to new advances.

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Welding

TECHNOLOGY

AUTUMN MEETING, 1958

Why Weld Automatically?

By I. C. Fitch, A.M.I.Mech.E., M.Inst.W.

SYNOPSIS

THE paper describes the technical and economic advantages of automatic welding methods, and gives examples of the different types of machines that can be used.

Specialized machines and the extensive use of manipulating equipment are illustrated.

SPECTACULAR advantages can be achieved by the use of automatic metal-arc welding in favourable circumstances, but its haphazard application can prove both costly and disappointing. It is advisable therefore to examine thoroughly any proposal to use this method of welding, and to consider all the relevant factors that are likely to contribute to its success. Certain aspects of importance might easily be overlooked and it is the object of this paper to consider the factors most likely to merit attention and to place them in perspective.

REASONS FOR ADOPTING AUTOMATIC WELDING

When considering whether automatic welding should be used it is advisable firstly to examine the objects in view and to place them in order of importance.

The most common reasons for adopting automatic welding are to:

(*a*) Reduce the cost of the product
(*b*) Improve the quality of the product
(*c*) Increase the rate of production
(*d*) Enable welding to be done by remote control
(*e*) Make welding easier.

Clearly, these reasons are to some extent interdependent but the emphasis on any one will determine to a large degree the type of equipment best suited to the work.

The importance of reducing the cost of a product needs no emphasis, but occasionally the problem is one of having to increase production and being handicapped by lack of space or shortage of skilled labour; in these circumstances cost may be of secondary importance.

Pressure vessels can be welded manually but most manufacturers of these vessels use automatic welding, primarily because of the consistency of quality that it gives. The high capital investment in equipment for this class of work is offset by savings, due to the elimination of the cost of re-welding and re-testing defective places in the welds that might otherwise be necessary.

When it is not possible to approach the work because it is at a high preheat temperature or is radioactive or must be enclosed in a gas chamber during welding, the demands made on the equipment may be exceptionally severe. The outlay on such unusually complicated equipment may be justified not so much by considerations of cost as by the ability to do the job at all.

It is often difficult to find sufficient labour of the right kind, and in these circumstances it may help to employ aids to welding which are by no means fully automatic, but which make welding easier to do.

It is evident that the best equipment to use will depend on the particular circumstances, and it is appropriate to consider the types of equipment available and their advantages and limitations.

WHAT IS AUTOMATIC WELDING?

The minimum requirement for automatic welding is that the arc length should be controlled. Commonly, the rate of travel of the arc along the joint is also controlled, as well as the angle of presentation of the electrode to the joint and its position in the joint.

An automatic welding machine may also have to:

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The author is in the Heating and Welding Engineering Dept. of Metropolitan-Vickers Electrical Co. Ltd.

(*a*) Strike the arc
(*b*) Fill the crater at the end of the weld
(*c*) Bring the welding head into position before welding and retract it afterwards
(*d*) Follow a joint of irregular contour
(*e*) Clamp the components together
(*f*) Eject the finished article
(*g*) Apply preheat and/or postheat to the weld.

Some of these functions are of a very specialized nature and machines that incorporate them are more akin to machine tools.

A fact that must not be overlooked is that in a skilled welder one has the most versatile means of controlling a welding arc because he can think and adapt his technique to accommodate such things as badly prepared joints, dirty plate, and welds in difficult positions. On the other hand, the standard of his performance is influenced by fatigue, and by virtue of his greater versatility there is, if it is wrongly applied, a greater possibility of error.

An automatic welding process will control one or more of the variables in welding and may control them to a more uniform standard than the welder, but it demands that the work presented to the machine is of a higher standard than that acceptable for manual welding.

How far, then, should one go towards fully automatic welding?

Touch welding

If the object is to make welding easier this can possibly be achieved by the simple expedient of touch welding, using what are known as contact electrodes. Such electrodes have been known for a long time but have not been widely used because in their original form the heavy coatings needed to make them suitable for touch welding restricted their use to a limited range of sizes of fillet welds. They were intolerant of rust and scale and demanded a higher standard of preparation than is normally required for manual welding. Recent developments, in which part of the coating has been replaced by iron powder, have resulted in electrodes that are more adaptable and have the advantage that they deposit weld metal faster than conventional electrodes. The way is thus open to a much wider use of contact electrodes.

It is a simple step from the manual use of a contact electrode to providing a means whereby the electrode is held in a chuck that is guided mechanically; it then becomes practicable for a welder to operate several such equipments simultaneously.

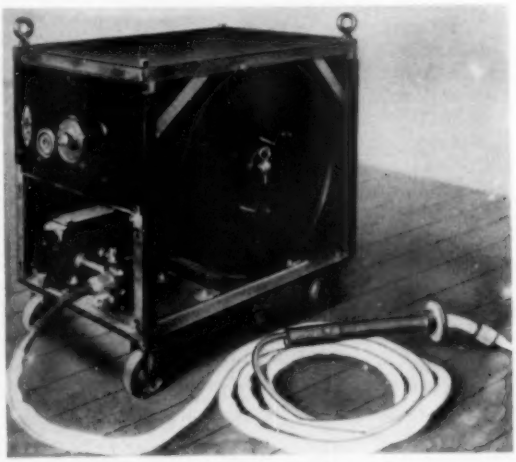
It soon becomes clear, however, that some of the advantage is lost because time is taken to set up the apparatus in its correct position relative to the joint, which must be well prepared, unobstructed, and preferably straight. Circumferential joints in cylinders can be welded if provision is made to rotate the job at the right speed.

Automatic welding using stick electrodes

It is a logical development to make an automatic welding machine that can use stick electrodes, which are cheap and are available in a wide variety of types. Such machines eliminate the difficulties due to operator fatigue and are most useful where the work is of a repetitive nature and where the joints require one electrode each. They may be used for continuous welding but the current that can be used is no greater than that for manual welding and some difficulty arises in making a sound junction between the weld of one electrode and that of the next. Tolerably good results can be achieved but the best is rarely as good as can be done manually by a competent welder.

Automatic welding guns

The feeding of an electrode from a coil to a welding gun so that a welder may weld continuously is an obvious step to increased welding speed. Figure 1 shows a machine made in 1932 for this purpose.



1—Early device for semi-automatic welding

The full advantage cannot, however, be realized unless the work can be moved past the welder as welding proceeds so that he does not need to stop to move himself and his equipment.

Several serious technical difficulties have beset this approach to continuous welding, and an examination of these is desirable before describing some of the many attempts to overcome them.

The first difficulty is to obtain a steady feed of the electrode. The steadiest feed results from an arrangement in which the feeding mechanism is in the gun, which then tends to become too heavy to be of practical value. When the wire is pushed through a flexible guide tube any resistance to its motion due to buckling causes a thrust in the tube, and this disturbs the welder. Furthermore, this condition limits the practical length of the tube to about 10–20 ft. so that the operator must remain close to the feeding mechanism which then becomes an encumbrance. The tubes tend to be worn rapidly by the friction of the electrode and to become blocked by particles of metal dislodged by the feed rolls or thrown back from the arc on to the nozzle, unless regular attention is paid to their cleaning and maintenance.

These problems are particularly acute if flux-coated electrodes are used. An electrode of sufficient size to be practicable to manufacture tends to be too stiff, and particles of flux dislodged in bending can further shorten the useful life of the tube.

Recent developments of this type of equipment have in common the use of a gas shield to protect the weld metal and the use of relatively small diameter electrodes. When filler wire of about $\frac{1}{16}$ in. dia. is used at approximately 130 amp and a current density of 50,000 amp/sq.in. the transfer of metal becomes a fine spray of droplets and the arc length becomes sufficiently self regulating to make it practicable to feed the filler wire at a constant speed, dispensing with automatic arc length controls. Such an arrangement has the advantage that variations of thrust on the gun are virtually eliminated and the small wire can be fed by a relatively light mechanism, although the inherent high lineal feed speed introduces problems with starting and stopping. To improve the degree of self regulation of the arc, welding sets have been introduced with volt-ampere relationships different from the conventional drooping characteristics. Some of these sets have flat or even rising volt-ampere characteristics, but though they improve the arc control they are unduly sensitive to variations in mains voltage or drift of machine voltage and therefore need the addition of a voltage stabilizer. Which combination of welding set and equipment is the best cannot yet be answered, but development in this field is active.

Results so far have been most successful in the welding of aluminium but it is natural that attempts should be made to apply the method to the welding of mild steel. In Britain argon and CO_2 gases have been used. Carbon dioxide is the cheaper gas and gives a higher welding speed, but the arc needs to be kept very short to avoid heavy spatter losses. At present the core wire needs to contain the correct amount of deoxidizer for the steel being welded. For this reason killed or semi-killed steels can be welded satisfactorily, but rimming steels, because of their inherent inhomogenity are difficult to weld with consistently satisfactory results. The high cost of the specially deoxidized wires and the unsatisfactory results on rimming steels are limiting the use of this method of welding.

Attempts to overcome this limitation have been made by introducing a flux either as a core to the electrode or as a powder carried by the shielding gas, but it is too early to judge how successful these methods will be.

A feature common to equipments using a small diameter filler wire is the deep penetration of the weld into the joint. This is an advantage for materials up to about $\frac{3}{8}$ in. thick since it permits joints to be made with less edge preparation. The turbulence caused by this deep penetration limits the maximum current that can be employed to about 275 amp for aluminium and about 400 amp for steel. The minimum current is fixed by the need to obtain a spray transfer so that the process is not suitable for plate below about $\frac{1}{8}$ in. thick.

Submerged-arc welding

The most successful solution of the problem of using high welding currents has been achieved by the use of an uncoated wire and a granular flux applied to the joint. In this method of welding the arc is completely submerged in flux and both the arc and the joint are invisible. Currents as high as 3000 amp can be used, though practical considerations limit the commonly used values to the range 200–1200 amp.

With this process there is no spatter, the welds have a very smooth profile and are of a high quality. For this reason, it has been extensively used for the construction of pressure vessels and it lends itself well to mass production. The process is complicated by the need to feed the flux to the joint and to remove the surplus after welding. Accurate preparation of the plates is essential and the process is adversely affected by rust or dampness. For these reasons it has not been widely used for outdoor construction in spite of its advantage in speed, although special machines have been built for the construction of oil storage tanks in which provision has been made to clean and dry the plate and render the equipment weatherproof.

The process is not limited to the welding of mild steel and it finds an application in reclaiming parts of earth-moving machinery, crusher rolls, and so on, using either alloy welding wires or additions of alloys to the flux.

Though equipment has been made for submerged-arc welding in which the welding head is guided manually, the skill required for consistently good results has caused most users to mount the head on some form of travelling carriage, or to use it with a manipulator.

Flux-coated electrodes

The invisibility of the arc and joint inherent in the submerged-arc method is a disadvantage when the path of the joint is irregular or the position of the electrode in the joint is critical.

In such circumstances, or where the welding is performed out of doors, flux covered electrodes are preferred. It is not a simple matter to design a flux coated electrode for automatic welding with the necessary provision for feeding the welding current into the electrode near the arc, and much ingenuity has been shown in the construction of such electrodes.

Unless the coating can be applied as the electrode is fed to the arc, some metal must be exposed to transmit the welding current, and the more metal that is exposed the greater is the loss due to spatter and the poorer is the arc stability. If the exposed metal is insufficient, arcing of the contacts limits the welding current that can be used. Currents commonly used fall in the range 200–750 amp, though higher values are permissible if the additional spatter can be tolerated. The use of CO_2 as a supplementary shielding gas has enabled the maximum current to be increased and has permitted the use of types of coating that otherwise gave poor quality welds at currents greater than 400 amp.

Combinations of processes

Mention has already been made of the use of fluxed electrodes combined with separately applied gas shields. Another interesting combination may be used for making deposits of alloy steels. When alloys are added to the coating of an electrode it becomes possible to deposit weld metal of a wide range of composition without recourse to the use of special core wire. Changes in arc length affect the losses of alloy, the longer the arc the greater being the loss, but within the normal range of operating conditions the composition of the deposit is relatively constant.

When alloys are added to submerged-arc fluxes the alloy content of the deposit increases as the arc length is increased because more flux is melted, and the composition of the deposit is thus more dependent on the welding conditions.

It has been found useful sometimes to combine the advantages of the fluxed electrode and the freedom from spatter and smooth weld profile of submerged-arc welding by using a fluxed electrode in conjunction with a submerged-arc flux.

CHOICE OF PROCESS

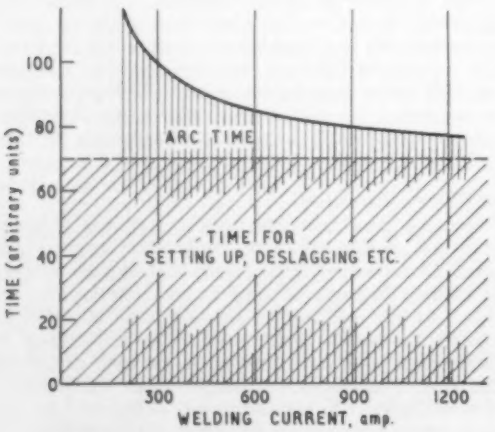
Though all have not been described, the wide range of automatic methods of welding that are available is apparent from the foregoing remarks.

A preliminary selection likely to be suitable for a given purpose may be made on their respective technical merits but consideration must also be given to several matters that are important, whichever process is chosen, if the best advantage is to be gained. The degree to which these requirements can be met will in its turn have a decided bearing on the final choice of method.

Duty cycles

In considering the advantage to be gained by automatic welding it is important to pay attention to the duty cycle at which the machine will operate. The machine may weld two or three times faster than is possible by manual welding, but if the time for setting up and ancillary operations remains the same as for manual welding the real advantage may not be very great.

If, for example, a comparison is made between manual welding at 300 amp and machine welding at 600 and 900 amp and the duty cycle for manual welding is assumed to be 30%, the advantage of welding at 600 amp will be only a 15% increase of speed and for 900 amp 20%, unless the lost time is also reduced as the welding speed is increased (Fig. 2). The faster the welding speed becomes, the less in proportion becomes the welding time, so that ultimately it pays better to invest in equipment to ensure a higher duty cycle rather than higher welding speed. An important advantage of automatic welding is that welding can be continuous. If this advantage is not to be lost attention must be paid to the elimination of interrupted welds such as those caused by gussets in girders. If possible, the articles to be welded should be fed to the machine so that the arc need not be broken, or arrangements should be made for double loading so that welding can proceed while fresh material is loaded into the machine.



2—Relation between arc time and setting-up time

Welding current limitations

Whatever may be the potential current with a given equipment its realization will depend on the type and position of the joint. The flat position gives the greatest freedom to use high currents, but with the welding of plate thinner than $\frac{3}{16}$ in. preparation of the joint becomes very critical if currents greater than 500 amp are to be used, and adequate clamping and the use of backing bars become essential for consistent quality.

A less obvious limitation arises with the welding of circumferential joints in horizontal cylinders. In this instance, the diameter of the cylinder must be sufficient to give adequate support to the molten pool so that the metal does not run out. At 1000 amp the minimum practical diameter is about 36 in., whereas at 500 amp it is about 5 in. Below 3 in. dia. the mass of the job plays an important part in determining whether it is possible to make such a weld continuously.

Welding head limitations

There is an advantage in automatic welding in using a small size of electrode because the penetration depth increases for a given current as the filler wire size is reduced. The lineal rate of feed of the electrode, however, increases as the inverse square of its diameter.

The range of electrode sizes that can be fed by a given welding head will be limited by its design, and this fact must not be overlooked when changing from one size of electrode to another, or when increasing the welding current.

The rate of feed of the electrode depends mostly on the current but is modified by the composition, the polarity of the welding current, and the length of electrode between the point of current feed and the arc. A rough guide to the feed rate is given by the following formula for steel.

$$\text{Feed speed (in./min.)} = \frac{0{\cdot}0022 \times \text{amp}^2}{\text{(electrode, dia., in.)}}$$

For aluminium the feed speed will be 50% greater. An adequate margin must be left between the maximum feed speed of the welding head and the working rate to permit the arc control to work satisfactorily. This margin should not generally be less than 15% of the maximum speed.

If a head designed for high-speed working is used at unduly low speeds difficulty may be experienced with hunting of the arc control, though this will depend on the type of control.

WELD PREPARATION

The higher welding currents made possible by automatic welding increase the depth of penetration and this must be considered in the preparation of the joints.

For a given electrode and welding current polarity, penetration is approximately proportional to current for welds on flat plate. Within the normal range of travel speeds employed, penetration does not change greatly, but welds sloping uphill penetrate more deeply and vice versa. In **V** preparations penetration cannot readily be measured, but the distance from the deepest part of the fused metal to the end of the electrode will be found to be approximately proportional to current. Too narrow a preparation can make the electrode withdraw from the root, since the arc tends to play on the sides and hence penetration may not be as deep as expected. The high penetration resulting from high welding currents permits close butt welds to be made in thicker plates, *e.g.* up to $\frac{3}{4}$ in. thick at 1000 amp, welding from both sides, with a resultant saving in weld metal and preparation costs.

In prepared butt welds a deeper root face can be used, thus reducing the amount of metal required to fill the joint and also permitting the use of a smaller included angle with a further saving in weld metal. The same advantages do not apply to **U** and **J** preparations.

The advantages of higher welding speeds and deeper penetration are partly offset by the need for greater accuracy in the preparation of the joint. The automatic machine will not adjust itself to variations in preparation and the higher the welding current the more critical becomes the preparation, particularly for the root run. The reason for this is that the molten pool becomes larger, and hence more difficult to control, as the welding current is increased. At the same time the risk of hot cracking of the weld increases, and for currents greater than 1000 amp plate quality becomes very important. For a close butt weld made with one run on each side it has been found that no gap is permissible if the penetration depth of the first run is greater than two-thirds of the plate thickness. It is very difficult to produce consistently satisfactory butt welds with full penetration from one side without using backing bars that are welded to the job.

WORK HANDLING

The importance of maintaining a high duty cycle has been stressed, but what are the means by which this can be achieved?

An essential requirement is that the welding head and the work can be brought together quickly, but which is to be made mobile will depend on the type of work. In shipbuilding it is common for the welding machine to be made to crawl over the work, but in a workshop it may be better to mount the head on a fixed or movable gantry alongside or spanning the working space. It is usual for cylindrical work to be supported on roller worktables adjacent to a gantry, which permits the head to be brought into position for circumferential joints or traversed to weld longitudinal joints. It is advantageous for the work to be prepared at a place to which the welding head can be moved as soon as it has finished the previous job. To enable this to be done it is sometimes worthwhile to duplicate all or part of the handling equipment, though this is a matter that depends on the relative costs of the welding and handling equipments.

The value of manipulators for turning the work so that manual welding can be done in the flat position is due partly to the higher welding currents that can be used in this position. In conjunction with an automatic welding machine the advantage can be even greater provided that the work is designed so that welding can proceed without interruption.

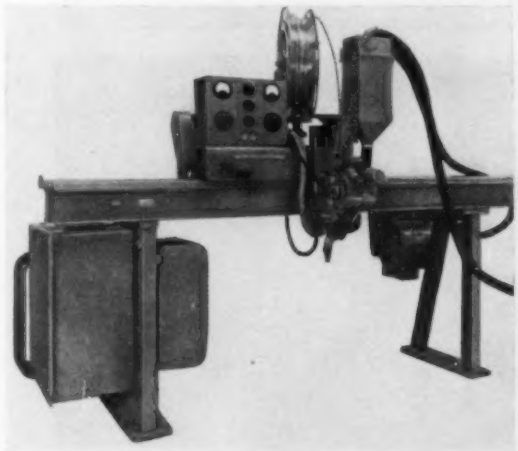
SPECIALIZED WELDING MACHINES

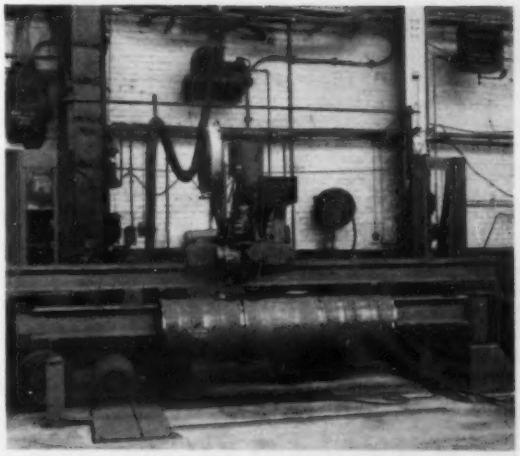
The extent to which an automatic welding machine and other equipment can be integrated for special purposes may be judged from the following examples.

Gantry mounted welding equipment

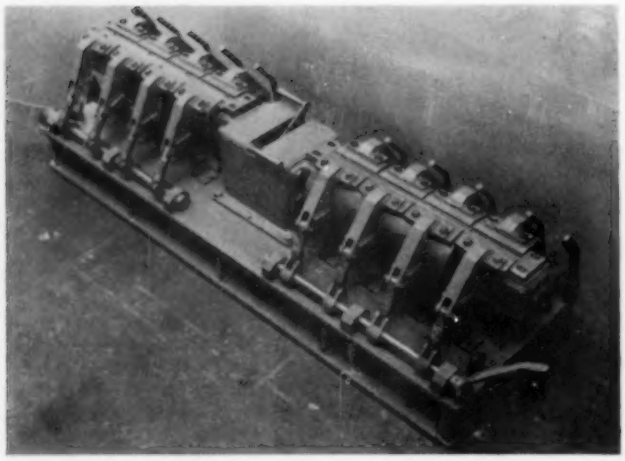
Figure 3 illustrates a simple gantry-mounted automatic welding head, the track of which is made in sections so that it can be extended to any convenient length. The operator's control panel is mounted on the carriage, which also carries the electrode reel and equipment for feeding and recovering submerged-arc

3—Simple gantry-mounted welding head

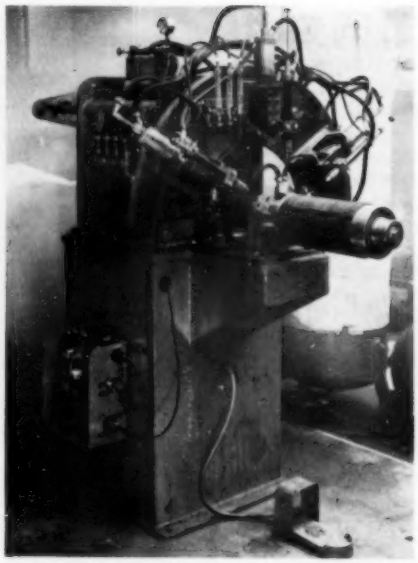




4—A series of cylinders being welded with a gantry-mounted head



5—Double loading jig



7—Argon-arc welding machine with triple heads

6—Special purpose manipulator used with a submerged-arc welding head

flux. The same welding head may be used for a flux-covered electrode or it may be replaced by an atomic-hydrogen or argon-arc welding head.

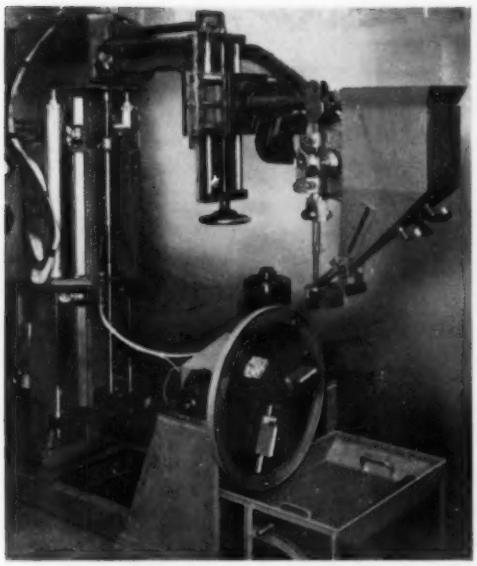
The head is shown mounted on a vertical slide to accommodate variations in work height. The main control cubicle is shown mounted on the gantry supports. Figure 4 shows an equipment of this type welding the longitudinal joint of several cylindrical shells. To make the best use of the equipment the shells are threaded on to a swinging beam and are tack welded to one another to present a joint for welding almost as long as the beam. On completion of the weld the shells are broken apart. By arranging for two such beams to be incorporated in the machine one set of cylinders can be assembled while the other set is being welded.

Double loading

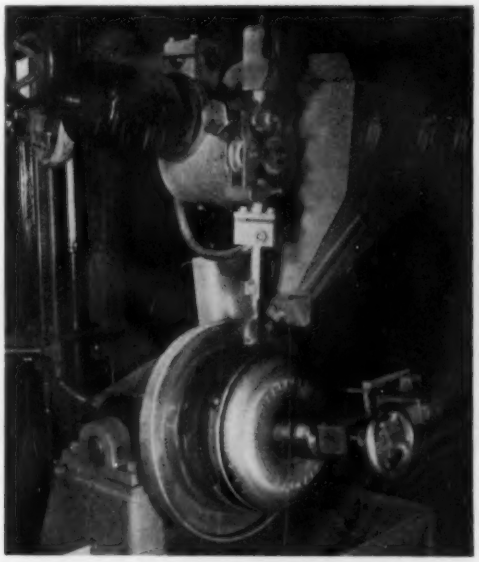
A double loading jig is illustrated in Fig. 5 for welding thin cylinders by the atomic hydrogen process. Correct fit of the joint is most important when welding thin sheet, for which provision is made in the design of the jig. One edge is first located against retractable pegs and is then clamped. The other edge is then butted against the first after the pegs have been withdrawn. The clamping jaws are made in sections, and the tension is individually adjustable by means of toggle links. When correctly adjusted the whole set of clamps can be closed by a master lever.

A more elaborate arrangement for the submerged-arc welding of tubular components to a mushroom shaped end piece is shown in Fig. 6. In this machine the welding head is mounted on a short track and is propelled by means of an air cylinder from one operating position to the other. The mushroom head of the assembly is located in a recess in the chuck that rotates the workpiece. The tube is located positively in its correct position relative to the head by means of retractable jaws fitted with rollers to permit limited rotation of the assembly. The tailstock also clamps the tube against the head. When the components are clamped in position the machine automatically carries out the following sequence of operations.

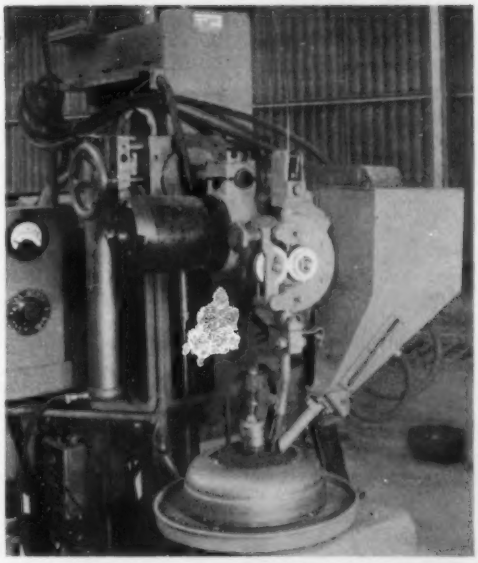
The welding head moves across to the welding position, the flux is allowed to flow on to the joint and the arc is then struck. When the arc is established the locating rollers retract and the clutch driving the mechanism for rotating the workpiece is engaged. Rotation continues until welding is complete, the time being controlled by a preset electronic timer, which extinguishes the arc after slightly more than one revolution of the workpiece, and stops the flow of



(a)



(b)



(c)

8—Small manipulator used with automatic head for welding variety of work

flux. While this is happening the completed component at the other station is ejected from the chuck and is removed by the operator who then loads the components of the next assembly. Means of collecting the unused flux and separating the slag from it are built into the machine.

Three-arc argon-arc machine

The manner in which means for assembly of the parts to be welded may be incorporated in the welding machine is further illustrated in Fig. 7. In this machine for argon-arc welding of stampings for the yokes of electric motors, several sets of stampings separated by copper discs are threaded on to a mandrel, with the slots aligned by means of locating blades. The mandrel is then expanded to align the parts axially, after which they are clamped together. The three argon-arc welding torches, which are fully retracted during loading of the machine, are then moved inward to strike the arcs on carbon blocks, retracted to the correct arc length, and traversed over the workpiece at full speed to their extreme outer position before being brought back at a controlled welding speed. On reaching the end of the workpiece the torches are brought to the resting position again at high speed. The workpiece is then rotated through 180° and three more welds are made, after which the torches are fully retracted and the welded components are released.

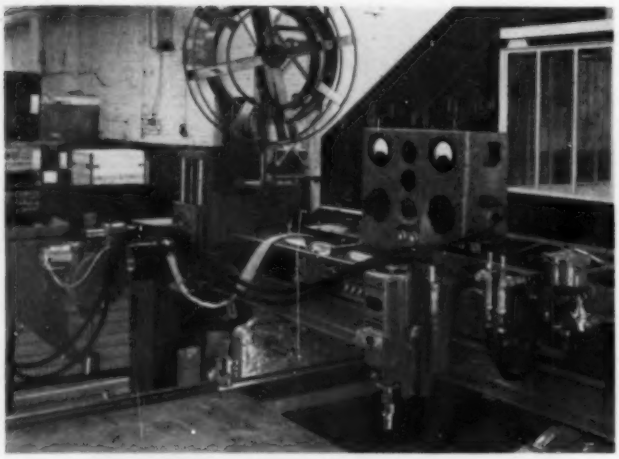
Manipulators

The use of a small manipulator in conjunction with an automatic welding head to weld a variety of jobs is shown in Fig. 8. The table of the manipulator has a variable rotational speed drive controlled from the operator's control panel and can be tilted to any angle between 0° and 90° to present the joint at the correct angle for welding.

The head is mounted on slides, which allow its position to be adjusted vertically, transversely, and fore and aft. In addition to these adjustments, provision is made for the head to be lifted clear of the job by means of a pneumatic cylinder, so that loading and unloading the job is unobstructed. The excess flux is collected in a bin placed beside the manipulator, provided with a screen to separate slag from the flux.

Profile welding

Figure 9 shows an automatic welding machine for welding complex shapes. In this, control of the movement of the welding head is by means of a profile



9—Welding head controlled by profile cutting mechanism

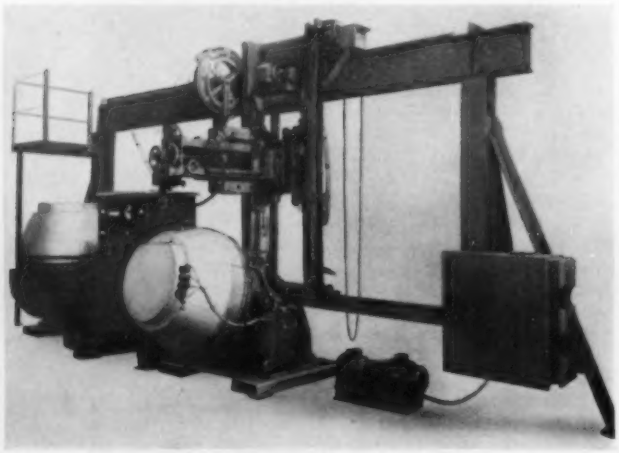
cutting machine mechanism. A template of the required shape is placed on the table with the workpiece alongside. Operation is them similar to that of a profile cutting machine except that the job needs to be more carefully aligned to avoid incorrect positioning of the arc relative to the joint.

Automatic preheat and postheat

A machine for building up the surfaces of worn crusher rolls is shown in Fig. 10. This not only has provision for double loading and makes use of manipulators for positioning the work but also has arrangements for automatically controlled preheating and postheating.

Each welding station is provided with a manipulator having a table which can be turned to the horizontal position to facilitate loading the rolls, which weigh about 6 cwt. When loaded, the oven (Fig. 11) is clamped over the roll and the table is tilted mechanically so that the conical face of the roll is level. The rolls are of high carbon alloyed steel and before welding they require to be preheated to 350°C. This operation takes three hours and so that it can be done before the start of the shift the heat is switched on automatically; the same temperature must be maintained for 2½ hr. after the completion of welding and this is also controlled automatically. The temperature is measured by means of a thermocouple in contact with the roll and is controlled at a preset value. When a roll is ready for welding the welding head is brought into position and lowered mechanically through a hatch in the oven casing. During welding the head is traversed to produce a helical weld, each turn overlapping the one before. Because the rolls are in the form of a truncated cone the speed of rotation needs to increase as the weld approaches the smaller end. Provision is therefore made for the speed to be adjusted automatically to maintain a uniform thickness of deposit. Over-riding controls are provided to permit irregularities in the wear of the rolls to be corrected.

11—Heat-treatment oven



10—Welding head and manipulator for hard-surfacing

CONCLUSION

No attempt has been made to discuss the cost of the various means of automatic welding, since values are continually changing. First cost is not necessarily a good guide, since a flimsy or poorly designed machine may be so troublesome that a reasonable performance cannot be achieved. A good approach is to consider carefully firstly what is required and then to determine which methods will meet the requirements. Relative costs should then be examined, bearing in mind any changes in works procedure that may be involved to make the best use of the equipment. If a good case can then be made, detailed quotations should be obtained to enable a final decision to be made.

WROUGHT nickel and the high-nickel alloys find many uses in the chemical industry. This paper reviews their major applications. The metallurgical and practical aspects of the materials are considered, with particular reference to maintenance of corrosion resistance across the welded joints.

The welding technique necessary to preserve the continuity of cladding is described for steels clad with nickel or high-nickel alloys. Mention is made also of the strip-lining of vessels and the use of overlay techniques as a means of economizing in use of materials.

Welding of Nickel and High-Nickel Alloys

IN THE CHEMICAL INDUSTRY

By J. Hinde, F.I.M., M.Inst.W.

To meet the demand for new products, or better quality in some already established, the chemical industry now requires specialized plant, which often operates at high temperatures and pressures. Such plant introduces many problems in selection of materials of construction, which must not only withstand the corrosive conditions involved, but also provide adequate properties at elevated or sometimes at sub-zero temperatures. Fabrication of such plant will make exacting demands on any welded joints.

Nickel and the high-nickel alloys find many applications in the chemical industry; some typical examples are illustrated in Figs. 1–6. This paper will be concerned with the welding aspects, and will deal only briefly with the major fields of service of these materials, about which much has already been published.[1]

MATERIALS UNDER REVIEW

There is widespread use of nickel-containing materials, such as the austenitic stainless steels, in chemical plant, but this paper will be concerned only with *nickel* and the *nickel-base* alloys. The composition of these materials and their more important properties are summarized in Table I.

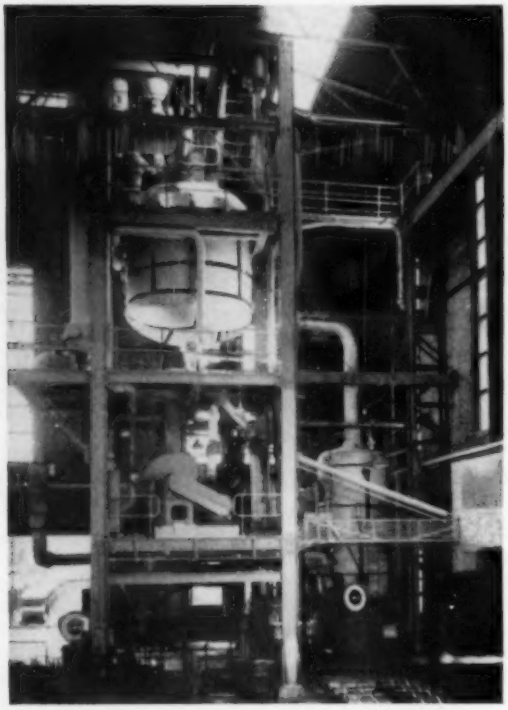
Several varieties of wrought nickel are available, but the composition quoted in Table I refers to the grade recommended for chemical plant involving welded fabrication. Such material finds widespread use in the concentration and handling of caustic alkalis, and also in the production and handling of phenol. In these applications the avoidance of metallic contamination or discolouration of the product is most important, especially when the chemicals are to be used in rayon or plastics manufacture. Welded equipment which will deal with highly concentrated caustic soda or will operate at temperatures above 310°C. should be fabricated from a grade of nickel with a maximum carbon content of 0·02%, in order to obviate the risk of intergranular attack.

The nickel–copper alloy shown in Table I has, for more than 50 years, been a standard material for use in chemical plant. Because of its copper content this alloy has better resistance than nickel to non-oxidizing chloride solutions and to hot dilute solutions of the non-oxidizing mineral acids (hydrochloric, sulphuric, and phosphoric). Many of the specialized applications of the nickel–copper alloy are in the handling of such acids, e.g. in the pickling of steel, in the production of ammonium sulphate, in the handling of sulphonated organic compounds for the production of detergents, and in processes operated in the petroleum-refining industry. This alloy also possesses good resistance to unaerated hydrofluoric acid. An addition of aluminium to the basic nickel–copper composition confers age-hardening properties on the alloy, whilst silicon additions to the cast form of the material increase resistance to galling. The corrosion resistance of these variants is much the same as that of the parent alloy, but neither of them is widely used for welded fabrication.

The nickel–chromium–iron alloy is much less resistant to hot chloride solutions and to non-oxidizing mineral acids, but is very much superior to nickel or the nickel–copper alloy under oxidizing conditions, and also possesses a high degree of resistance to a wide range of organic compounds. This latter attribute renders the nickel–chromium–iron alloy very useful in processes involved in the high-temperature splitting of fats and the production of vitamins and antibiotics, where metallic contamination must be avoided. This alloy finds its most significant applications in the high-temperature field; it is much used, for example, where resistance to ammonia atmospheres or halogen-containing gases is required. Considerable interest has been aroused in this material for handling high-purity water at the high temperatures and pressures encountered in nuclear engineering.

The nickel–molybdenum alloys have been developed to resist hot strong hydrochloric acid, under conditions where the only other wrought material likely to be

Paper presented at the Public Session of the Vienna Assembly of the International Institute of Welding, June 1958. Mr. Hinde is a member of the Development and Research Department of The Mond Nickel Co. Ltd.



1—Caustic-soda evaporator in low-carbon nickel

useful is tantalum or perhaps a precious metal. These alloys cannot, however, be used under strongly oxidizing conditions, and it was a logical approach to add chromium to the basic composition in order to provide resistance to oxidizing media. The nickel–molybdenum–chromium alloys will resist wet chlorine and many oxidizing salts under conditions where most wrought materials, except perhaps tantalum or titanium, would fail to give a useful life.

The final class of alloy to be considered is the nickel–chromium–molybdenum–iron group. This type represents an attempt to fill the gap between the usual austenitic chromium–nickel stainless steels and the high-nickel alloys. Examples of the application of these materials will be found in the handling of sulphuric acid, in concentrations up to 70% at 80°C., and in contact with sulphurous, phosphoric, nitric, and many of the organic acids.

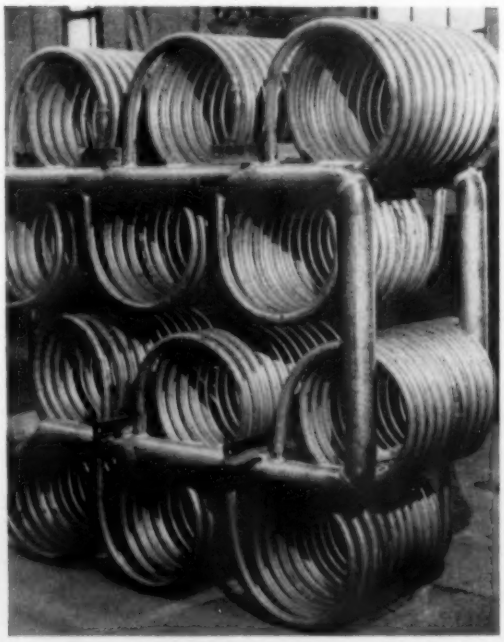
There are many instances where the use of one of the alloys under review is essential to obtain maximum corrosion resistance or to preserve purity of product in circumstances where considerations of mechanical design demand a thickness of material which would render the equipment very costly. In such cases the required total thickness may be such that an economic compromise may be effected by the use of a mild or low-alloy steel clad with a layer of nickel or the appropriate high-nickel alloy.[2] An alternative to the use of clad steels may be strip lining, a procedure well established in the petroleum-refining industry, or the use of welded overlays.

METALLURGICAL ASPECTS OF WELDING

The metallurgy of the welding of nickel was the subject of a paper submitted to the 1957 I.I.W. Assembly,[3] but it is proposed to refer again to certain aspects which are of particular moment in relation to welded chemical plant. Cleanliness of the parent material is necessary for sound welds in any material, but particular importance attaches to the possible contamination of nickel and its alloys by sulphur-containing materials. Frequent reference has been made in the literature to this hazard, but it can easily be avoided by intelligent application of simple cleaning methods prior to welding,[4] as evidenced by the illustrations of fabricated plant which accompany this paper. Nickel and the nickel–copper alloy, if stored for long periods in an industrial atmosphere, may acquire a sulphur-containing patina, and mechanical cleaning will be necessary to remove this film; de-greasing will not be sufficient.

All the usual welding processes may be applied to the materials under review, but those mostly used for fabrication of chemical plant are the oxy-acetylene, metal-arc, and inert-gas metal-arc methods. There are no official specifications for filler wires or electrodes for the nickel–chromium–molybdenum–iron alloys, but suitable materials are generally available from the suppliers of these alloys. There are AWS–ASTM specifications for the other alloys, and these have been summarized in Table II, which also carries reference to certain British specifications.

So far as the mechanical properties of welded joints are concerned, it may be taken that all the filler materials will provide joints having tensile properties



2—Heating coils in nickel for treatment of edible fats

similar to those of the annealed parent materials. Where these materials are used for pressure vessels and related applications it will be necessary to meet Code requirements. A useful survey of such requirements, including strength/temperature relationships, is contained in a Welding Research Council Bulletin.[5]

Perhaps the most significant feature, when comparing the chemical composition of the weld deposits in Table II with those of the parent material in Table I, is the high carbon content apparently permitted for joining nickel to nickel. The deposit made by the E3N11 electrode contains, however, sufficient titanium to combine with the carbon and thus prevent graphitization and the formation of intergranular films. The electrode coatings create a strongly reducing atmosphere, across which it is possible to transfer to the weld deposit a sufficient quantity of the easily oxidizable titanium. This E3N11 electrode will develop adequate ductility in the joint except perhaps in circumstances which involve iron dilution; in that case the ductility will be definitely lower (although still of the order of 20%). The low-carbon E4N11 electrode was therefore developed for overlays on nickel, the welding of nickel-clad steels, or the joining of nickel to steel. This modified electrode will give adequate ductility in such circumstances of iron dilution.

With the nickel–copper composition the risk of graphitization is much less, but the effect of iron dilution assumes greater significance. When the E3N10 deposit is diluted by iron, actual weld cracking will ensue. The use of the low-carbon E4N10 type is, therefore, essential when welding clad steels, for the strip lining of vessels, for the deposition of overlays, and for the joining of nickel–copper alloys to steel.

The difference between E3N12 and E4N12 is mainly in the chromium content: the latter type will permit more dilution by iron before the chromium content falls below about the 12% figure which is regarded as the minimum for ensuring adequate corrosion resistance. This E4N12 electrode must be used for joining a number of dissimilar-material combinations of the nickel–chromium–iron type. However, a special nickel–chromium–iron electrode has recently been developed specifically for the welding of a wide range of dissimilar-metal combinations. This new electrode is not yet covered by any official specification.

So far as nickel, and the nickel–copper and nickel–chromium–iron alloys are concerned, the heat-affected zone produced by welding does not normally introduce any hazard such as weld decay or peak hardening, and neither preheat not post-heating is required. In the nickel–molybdenum and nickel–molybdenum–chromium alloys, a grain-boundary precipitate may occur, an effect associated

Table I

Composition and Properties of Nickel and High-Nickel Alloys in the Annealed Condition

Material	*Nominal Composition, % max. unless otherwise stated*									*0·2% Proof Stress, tons/in²*	*Max. Stress, tons/in²*	*Elong. % on 2 in.*	*Typical Hardness Values, D.P.N.*	*Approx. Melting Range °C.*	*Specific Heat, (c.g.s) 20–100 °C.*	*Therm. Cond., (c.g.s) 20–100 °C.*	*Coeff. of Exp., (c.g.s. ×10⁻⁶) 20–500°C.*	*Annealing Temperature, °C.*
	*Ni**	*C*	*Si*	*Mn*	*Fe*	*Cu*	*Cr*	*Mo*	*Other Elements*									
Nickel	99·0† min	0·15	0·15	0·35	0·4	0·25	—	—		8	30	45	110	1435–1455	0·110	0·145	16·5	815–925 air cool
Nickel-copper alloy	63·0	0·3	0·5	2·0	2·5	28–34	—	—		12	34	45	135	1300–1350	0·127	0·062	16	870–980 air cool
Nickel–chromium–iron alloy	72·0	0·2	0·5	1·0	10	0·7	14–17	—		15	40	40	140	1395–1425	0·109	0·036	15·5	980–1065 air cool
Nickel–molybdenum alloys	Bal	0·1	1·0	1·0	5·8	0·4	—	26–30		28	60	40	250	1345–1370	0·09	0·027	12	1150–1175 rapid cool
Nickel–molybdenum–chromium–alloys	Bal	0·1	0·1	1·0	4·7		14·5–16·5	15–17	3–4·5W	30	60	40	250	1270–1300	0·092	0·025	14	1210–1230 rapid cool
Nickel–molybdenum chromium–iron alloys	* 40·0	0·05	0·5	1·0	31	1·25	21	3		14	40	57	150	1280–1320	0·10‡	0·03‡	17‡	1120–1150 rapid cool
	† 45·0	0·05	1·0	2·0	13·5–17·5	—	21–23	5·5–7·5	1·75–2·25Nb	22	45	46	170	1270–1300	0·10‡	0·03‡	17‡	1150–1175 rapid cool

* Includes residual cobalt. † Carbon content 0·02% max. in low-carbon quality. ‡ Estimated values.

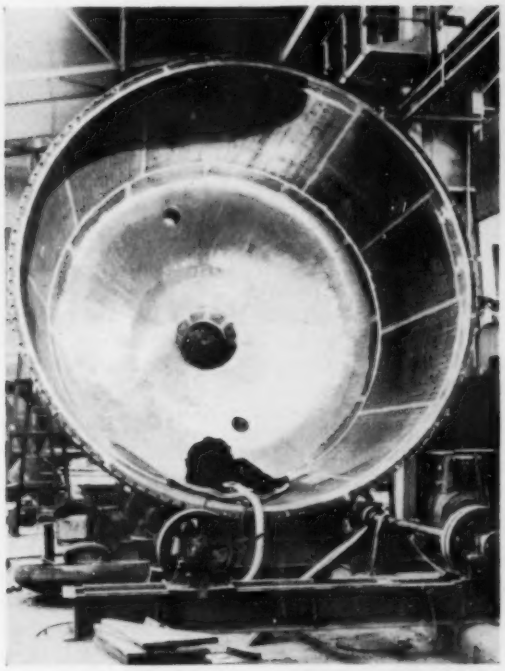
Table II

Filler Wires and Electrodes for Welding Nickel and High-Nickel Alloys

Process and Specifications	*Material*	*AWS–ASTM Classification*	*British Standard Classification*	*Composition, % (max. unless otherwise stated)*										
				C	*Mn*	*Fe*	*Si*	*Cu*	*Ni*‡	*Al*	*Ti*	*Cr*	*Mo*	*Other Elements*
Oxy-acetylene Welding ASTM.B304–56T AWS.A514–56T	Nickel	RN 41	—	0·15	0·35	0·4	1·0	0·25	97·0 min		0·5			
	Nickel–copper	RN 41	—	0·30	2·0	2·5	0·5	Bal	63–70					
	Nickel–chromium–iron	RN 42 †	—	0·1	1·0	6·0–10·0	0·5	0·5	72·0 min			14·0–17·0		
Argon-arc and inert-gas metal-arc welding ASTM.B304–56T AWS.A514–56T BS.2901:1957	Nickel	ERN 61	NA 32	0·15	1·0	1·0	0·75	0·25	93·0 min	1·5	2·0–3·5			
	Nickel–copper	ERN 60	NA 33	0·15	1·0	2·5	1·5	Bal	62·0–69·0	1·25	1·5–3·0			
	Nickel–chromium–iron	ERN 62 †	*see* note	0·10	1·0	6·0–10·0	0·75	0·5	70·0 min			14·0–17·0		1·5–3·0 Nb
	Nickel–molybdenum	ERN 7B	—	0·08	1·0	4·0–7·0	1·0		Bal			1·0	26·0–30·0	0·2–0·6 V
	Nickel–molybdenum–chromium	ERN 7C	—	0·08	1·0	4·0–7·0	1·0		Bal			14·5–16·5	15·0–17·0	0·035 V 3·0–4·5 W
Metal-arc welding ASTM.B295–54T AWS.A511–54T	Nickel	E3N 11	—	0·75	0·75	0·75	1·25	0·25	92·0 min	1·0	0·5–4·0			
		E4N 11 *	—	0·10	0·75	0·75	1·25	0·25	92·0 min	1·0	1·0–4·0			
	Nickel copper	E3N 10	—	0·4	4·0	2·5	1·0	Bal	62·0–70·0	1·5	1·0			
		E4N 10 *	—	0·15	2·5	2·5	1·25	Bal	68·0 min	0·75	1·5			3·0 Nb
	Nickel–chromium–iron	E3N 12	—	0·15	1·5	11·0	0·75	0·5	68·0 min			13·0–17·0		1·5–4·0 Nb
		E4N 12 *	—	0·15	1·5	4·0	0·75	0·5	70·0			17·5 min		1·5–4·0 Nb
	Nickel–molybdenum	E3N 1B E4N 1B	—	0·12	1·0	4·0–7·0	1·0		Bal			1·0	26·0–30·0	0·6 V
	Nickel–molybdenum–chromium	E3N 1C E4N 1C	—	0·12	1·0	4·0–7·0	1·0		Bal			14·5–16·5	15·0–18·0	0·35 V 3·0–4·5 W

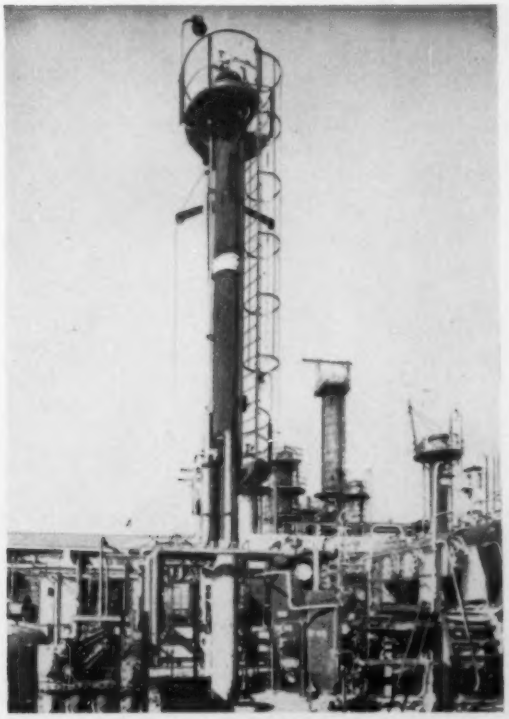
Note: (*) = Used under conditions where weld deposit will be diluted by iron. (†) = An 80–20 Ni–Cr wire known as NC 82 is used in Europe and is covered by BS. 2901: 1957 Grade NA 34.
‡ Includes residual cobalt.

3—Press roll in Monel 2¾ in. thick made by metal-arc welding three sections



5—Nickel vessel for salt evaporator and crystallizer

4—Inconel-clad steel reactor, Dowtherm heating



6—Stripper column in Monel

with incipient fusion immediately adjacent to the weld deposit. In severe service conditions the sensitized zone may be attacked. The precipitate can be eliminated by a post-welding heat-treatment involving a very rapid quench from the annealing temperature. Since in oxy-acetylene welding more heat input, over a longer time, is required, this method is not recommended for the nickel–molybdenum and nickel–molybdenum–chromium alloys, because of the greater risk of producing this undesirable precipitate.[6] The nickel–chromium–molybdenum–iron alloys are not subject to weld decay in the corrosive media for which they are normally recommended, but in the welding of these alloys or the nickel–chromium–iron type by the oxy-acetylene or carbon-arc process it is desirable to prevent carbon pick-up, which may affect the general corrosion resistance of the deposit.

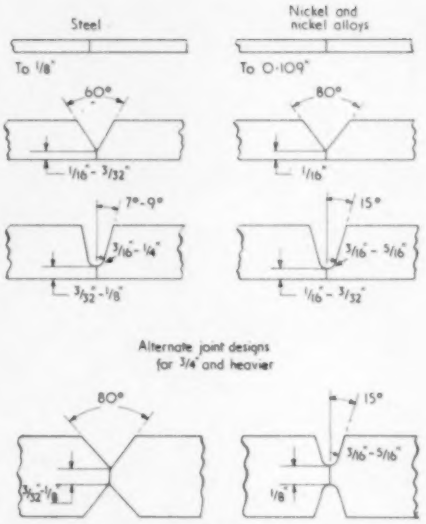
PRACTICAL ASPECTS OF WELDING

The molten weld metal produced in the joining of nickel and the high-nickel alloys is less fluid than that characteristic of steels, and it does not penetrate so deeply. For this reason, a somewhat more open joint preparation is necessary for nickel and its alloys, in order to allow for manipulation and correct deposition of the weld metal. Figure 7 illustrates the difference in weld preparation between steel and the materials under review. The importance of cleanliness has already been emphasized: contamination may cause trouble, not only with the weld metal but in the heat-affected zone of the parent material.

Oxy-acetylene welding was once standard for light-gauge materials, but for the lighter chemical plant fabricated in the materials now under review that method has been largely superseded by the argon-arc process. The metallurgical risks involved in the oxy-acetylene welding of nickel–molybdenum and nickel–molybdenum–chromium alloys have already been mentioned. Nevertheless, oxy-acetylene welding still remains a useful method for site work, and for repair welding, and in cases where there may be difficulty of access. Some notes on general procedure are, therefore, given below.

A neutral flame is desirable for nickel and nickel–copper, but one which is very slightly carburizing is more practicable to maintain, since any tendency to oxidizing conditions must be avoided. For the chromium-bearing alloys the flame needs to be more definitely carburizing, but not to the extent of involving any risk of carbon pick-up. Flux is unnecessary for nickel, but for the other materials suitable fluxes are available. These compositions are based on freedom from boron compounds, since these can form low-melting-point constituents which may cause cracking in the weld deposit, particularly with the chromium-bearing alloys. The most important difference from steel-welding practice is the avoidance of any puddling of the molten weld pool, because such agitation burns out the residual deoxidants and causes unsoundness of the deposit. Appropriate filler wires for use with the oxy-acetylene process are given in Table II.

The filler wires for argon-arc welding are also listed in Table II, and it is important to note that for nickel and the nickel–copper alloy these differ from the filler



7—Comparison of joint design in steel and in nickel alloys

wires used in oxy-acetylene welding, particularly in the high titanium content. It is imperative that these '60'-series filler wires be used for argon-arc welding or inert-gas metal-arc welding, otherwise porosity develops, a defect which is thought to be the result of a reaction between carbon and residual oxygen.[7] Where autogenous welding is unavoidable, an automatic process, maintaining a very short arc length, or the addition of hydrogen to the argon, will help, but the introduction of at least 50% of the correct filler wire into the deposit, and adequate flow of argon, are most effective in producing sound welds.

Standard equipment may be used for the argon-arc welding of nickel and the high-nickel alloys, and the techniques broadly follow accepted practice. The use of superimposed h.f. current at the start of a weld, and current-reducing devices for limiting crater cracking at the end of a run, are both in line with conventional practice. Starting and finishing tabs are also frequently used. Backing bars are employed in the usual way, often with an independent flow to the weld. Where backing bars are difficult to use, refractory materials and metallic tapes have been tried, with some success, for the purpose of underbead control. The '60' series of wires, layer-wound on spools, are used for the inert-gas metal-arc process, and such spools may be used also where an automatic feed of filler wire is required in the tungsten-arc process. For the inert-gas metal-arc welding of the nickel-base materials, standard techniques may be applied to give welds of appropriate mechanical properties and corrosion resistance. The main advantage of this process is that of speedier production, a feature which can best be utilized where relatively large amounts of welding are involved.

For the fabrication of chemical plant in nickel and nickel alloys of greater than $\frac{1}{16}$ in. thickness, metal-arc welding, with the coated electrodes listed in Table II, is the most popular method. All these electrodes are

designed for use on direct current, with the electrode connected to the positive pole. The basic principles of metal-arc welding are the use of a short arc, current towards the lower end of the recommended range, and a slow welding speed. Undue weaving of electrodes must be avoided: a useful rule is not to exceed three times the diameter of the electrode. High welding currents and fast rates of welding are factors which tend to overheat the electrode, leading to loss of arc control and consequent unsound deposits. Welders not familiar with the materials under review often use a high current in an endeavour to promote fluidity or to weld at the rate usual for steel, which is some 15% faster than that suitable for the nickel alloys.

Wherever possible the work should be arranged for downhand welding, although the nickel and nickel–copper electrodes can generally be used for welding in position.

QUALITY OF WELDING

In addition to the metallurgical and practical aspects of producing a sound weld which have been reviewed above, other aspects of weld quality have to be considered in the fabrication of chemical plant. Penetration of the weld should be uniform, and on heavier sections it is best to use a cover pass on the root side. In any weld the deposited metal has a metallurgical structure different from that of the parent metal, but assuming that the correct material has been used to make the weld, and that the deposit is sound, the joint will nevertheless have quite satisfactory corrosion-resistance. This is amply confirmed by field experience with welded chemical plant.

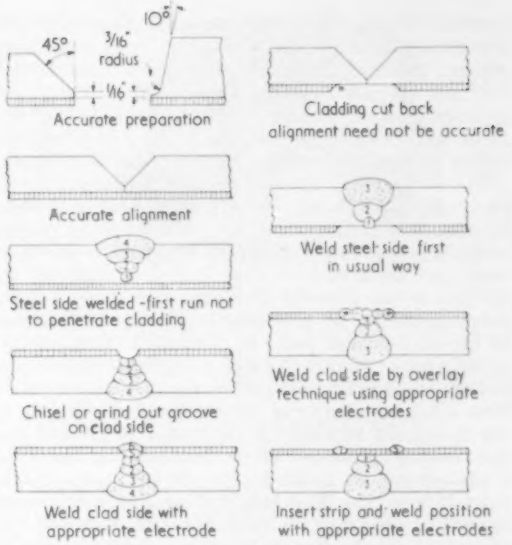
Surface finish is often a significant factor. In some instances the required degree of finish will be achieved only by mechanical polishing, but without going to this extreme much can be done to provide a finish suitable for the more general applications. It is important to pay attention to faults such as undercutting, ugly re-strikes, and poorly contoured weld beads, since these features may lead to local corrosion or perhaps to retention of material likely to affect the quality of the product.

Apart from any question of welding, the parent material should be carefully handled during fabrication, to prevent mechanical damage, particularly during rolling or pressing. Such damage may be of a gross kind, leaving obvious scratches or dents, but it may be more insidious; for example, steel particles from tools may be pressed into the surface. Foreign material may dissolve out in service, to contaminate the product, to cause local electrochemical effects, or to initiate pitting.

The complete removal of welding flux or slag is a matter of good housekeeping. The removal of fluxes or slags from welds intended for high-temperature service is particularly important, since there may be a metal–slag reaction under service conditions.

USE OF CLAD STEELS, LININGS, AND OVERLAYS

Chemical plant often requires the use of one or other of the high-nickel alloys to meet specific corrosive conditions, but in some cases the size and thickness of material necessary to ensure the required strength would make the plant very costly. Fortunately, to meet such circumstances, steels clad with nickel, and nickel–copper and nickel–chromium–iron alloys are readily available. Cladding with the other high-nickel alloys under review is as yet only in the experimental stage. In welding the clad steels, three methods of preparation are in use, as illustrated in Fig. 8. The objective of any preparation is to maintain the continuity of the cladding at the welded joint. Clad steels are not usually produced below $\frac{3}{16}$ in. overall thickness, or with a cladding less than 0·03 in. thickness. It is usual to express the cladding as a percentage of the total thickness of the plate (e.g. 10%, 15%, or 20%), although even on the thickest plate the cladding is seldom more than $\frac{1}{4}$ in. thick. The thinner the cladding, the more difficult it is to maintain its continuity without risk of trouble at the fusion zone. In some instances an all-alloy weld may be made, but more usually the thickness of the plate justifies the use of a steel deposit for the welding of the base material. In the method shown on the left-hand side of Fig. 8, accurate preparation and alignment are most important, but where the cladding is cut back prior to welding, such a high degree of accuracy is not necessary. Whichever preparation is used, the greatest difficulty arises with the weld deposit on the clad side, which is likely to become contaminated with iron. The importance of special electrodes for such welding has already been emphasized, but obviously in neither nickel nor the nickel–copper alloy is it possible to balance the iron pick-up by any adjustment of the composition of the electrodes. The E4N series of electrodes take care of the welding attributes but do not prevent iron dilution. A multi-run technique is, therefore, necessary to ensure that the surface layer of the weld is low in iron. The author has dealt with this subject in much greater detail elsewhere.[2]



8—Welding sequence for joining clad steels

The lining of steel vessels is a method extensively used where a continuous bond between the lining and the shell is not necessary. The choice of lining thickness

depends not only on the expected rate of corrosion but also on the nature of the fabrication: very thin linings require extremely accurate fitting and considerable skill on the part of the welder. Most linings are installed by a strip-lining procedure, using strips 3 in.–12 in. wide, of a length suitable for easy handling and fitting, and usually not less than 16 s.w.g. in thickness.

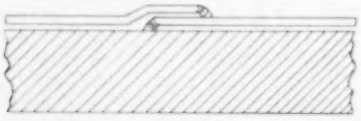
The lining pieces are shaped to follow accurately the curvature of the vessel, and are firmly held in position by some method of jacking. There are three recommended procedures for welding the strips in position: these are illustrated in Fig. 9. The shingle or lap method is the simplest and least expensive, but the irregular surface so produced is often a disadvantage so far as chemical plant is concerned. This method permits easier testing through a single air connection, but the construction may allow the corrosive medium from any leak to spread behind the entire lining. In the three-bead method the strips may be applied and tack-welded before any of the final welding operation is carried out. If, however, the gap between adjacent strips is large, the third bead will obviously be subject to considerable iron dilution. The advantages of this procedure are the ease of fit-up and the possibility of employing more than one operator at the same time. In the two-bead method the first strip is located in place and fully welded into position. Before applying the next strip, the weld must be completely de-slagged and any spatter or imperfections removed from the toe of the weld. The next strip is then butted to the first weld, the closure weld is made, and this operation is repeated until the lining is complete. When this procedure is used, welding skill of a high order is required for the best results, but it has the advantage that iron dilution of the weld deposit can be kept to a minimum.

Testing of strip lining may involve an individual pressure test on each strip and it will, of course, be necessary to close any test holes by welding. Since strip lining also involves the problem of iron dilution, it is necessary to use the E4N series of electrodes.

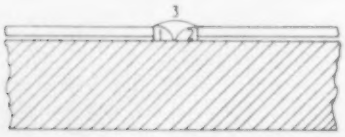
In plant where clad steels or linings have been used it may be necessary to deal with flanges and the like by an overlay technique, and this procedure may be used also for the actual lining of vessels. The overlays are generally deposited by the metal-arc process, and therefore require the use of the E4N series of electrodes The lower penetration characteristics of some of these electrodes may reduce iron dilution, but will certainly not eliminate it. Where iron dilution is significant it will, therefore, be necessary to adopt a multi-layer technique, the number of runs depending upon the amount of iron that can be tolerated in the final deposit.

The inert-gas metal-arc process has obvious attractions as a method of depositing overlays in production conditions, but its use on the high-nickel materials is not yet widespread.[8]

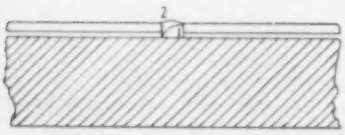
Finally, mention should be made of the recent development of electrodeposited nickel-on-steel sheets.[9] The deposit is normally only about 0·01 in. thick, which makes it extremely difficult to maintain the continuity of the coating at a weld, but for certain applications involving mildly corrosive conditions, such as the handling of sugar solutions, this type of material has proved useful. Some welded steel plant has been coated with nickel by electrodeposition in the conventional manner, and also by the more recently developed 'electroless' processes.[10]



(*a*) Shingle or lap joints



(*b*) Three-bead method



(*c*) Two-bead method

9—Joint design for strip lining

ACKNOWLEDGMENTS

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Thanks are also due to the following companies for permission to reproduce photographs: Murgatroyd's Salt and Chemical Co., Ltd. (Fig. 1); Southern Oils Ltd. (Fig. 2); Youngstown Welding and Engineering Co., Ltd. (Fig. 3); H. Bertram, A.G. (Fig. 4); Power Gas Corporation (Fig. 5); and the Lobitos Oil Refinery (Fig. 6).

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Welding

RESEARCH

Ageing Characteristics of 'As-deposited' Aluminium Alloy Weld Metal

WITH PARTICULAR REFERENCE TO Al–Cu–Si AND Al–Zn–Mg ALLOYS

By P. T. Houldcroft, B.Sc., and F. Fidgeon, B.Sc.

SYNOPSIS

WELDED joints in high-strength heat-treatable aluminium alloys normally have lower strengths than either the parent metal or the heat-affected zone. The very rapid cooling of weld metal when arc welding is employed gives a deposit which is virtually in the solution heat-treated condition. It appeared possible, therefore, that by controlling the chemical composition of the weld bead and applying a suitable precipitation treatment a stronger weld could be obtained.

The report describes the work carried out on two aluminium alloys and suggests that when welding Al–Cu–Mg alloys it would be profitable to age the welded assembly artificially. To avoid over-ageing the parent material it would probably be an advantage to weld solution heat-treated material and not fully heat-treated material. There is a possibility of developing filler alloys for Al–Zn–Mg parent material to give weld beads that will age satisfactorily, though sluggishly, at room temperature. With these alloys the parent material would be welded in the fully heat-treated condition.

Introduction

WELD metal deposited by arc welding is cooled at a high rate from the molten weld pool temperature, so that constituents are to a large extent retained in solution. In an 'as-welded' joint in a heat-treatable aluminium alloy, the weld bead and the adjacent parent metal are virtually in a solution heat-treated condition, and the properties of these regions can be improved by a simple ageing treatment. Even when filler metal is used, which in itself is not susceptible to heat treatment, sufficient alloying elements are usually picked up from the parent metal to make the weld bead susceptible to heat treatment and ageing.

The weakest part of a welded joint in high-strength heat-treatable alloys is normally the weld bead and not the over-aged region remote from the weld. Higher joint strengths might be obtained, therefore, if the properties of the weld bead were improved. One way of improving the strength of weld metal would be to increase its response to ageing by adjusting the composition with the correct choice of filler material. The weld bead composition must also have an adequate resistance to weld cracking, however, so that, in the development of new filler material, data on cracking and ageing behaviour must be considered together.

The ageing behaviour of weld metal, deposited from a number of standard and experimental filler

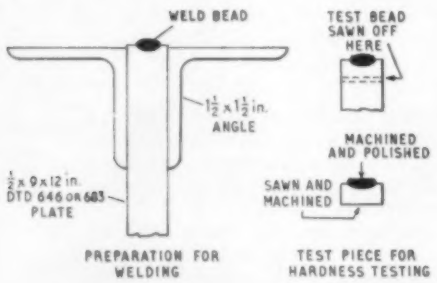
Report LM8/25/58 of the British Welding Research Association, issued to members in February 1958.

Mr. Houldcroft is Chief Metallurgist with the Association. Mr. Fidgeon, formerly in the Metallurgical Dept. of the Association is now Lecturer in Metallurgy at the Luton and South Bedfordshire College of Further Education.

metals, has been investigated by hardness testing weld beads laid on solid plate, since the testing of actual welds would have been too costly in time and material. With several filler materials the 'as-deposited' weld metal, suitably aged, reached a hardness approximating that of the unaffected parent metal. This could be of considerable importance in practice, because although large welded structures cannot generally be solution heat treated, there are many applications where artificial ageing after welding could be practicable. The possibility of welding material in the solution heat-treated condition and ageing the whole welded assembly appears to be promising. It is emphasized that ageing behaviour is only one property of weld metal which must be considered when investigating the suitability of an alloy for use as a filler metal.

EXPERIMENTAL PROCEDURE

Because of the large number of filler alloys for investigation, it was necessary to use a simple and economical method of depositing the weld metal. This had to give dilution and thermal conditions comparable with those existing in practice. To avoid the preparation of plate edges, bead-on-plate deposits were made, but it was naturally impossible to lay more than a single bead on each piece of plate, because the heat


WELD BEAD
TEST BEAD SAWN OFF HERE
1½ x 1½ in. ANGLE
MACHINED AND POLISHED
½ x 9 x 12 in. DTD 646 OR 683 PLATE
SAWN AND MACHINED
PREPARATION FOR WELDING
TEST PIECE FOR HARDNESS TESTING

1—Preparation of samples for ageing tests

from the second bead would affect the first. The method adopted was to lay a bead along the edge of ½ in. thick plate, held vertically as shown in Fig. 1. After welding and allowing the plate to cool, the weld bead was cut off, exposing a fresh edge for the next weld bead.

Weld beads were deposited on either L71 or DTD 5050 plate according to the type of filler alloy, using a standard argon-arc torch with a $\frac{5}{32}$ in. dia., plain tungsten electrode and a current of 160 amp. Steel angles on each side of the test plate provided backing for the argon shield. The filler rod was 10 s.w.g. The dilution was measured from microsections and varied between about 30 and 55%, thus covering the range likely to be encountered in fillet welds and prepared butt welds. As some difficulty was experienced in obtaining consistent dilution values an estimate of the weld bead composition was made in each test.

A 3 in. long piece was cut from each 12 in. machined and polished weld-bead sample for natural ageing tests. The remainder of each sample was cut into ½ in. long pieces for artificial ageing tests, which were carried out for various times at temperatures within the range normally specified for the parent metal, that is, 160–200°C. for L71 and 110–140°C. for DTD 5050.

All the results reported are the average of five hardness impressions.

MATERIALS

With the Al–Cu–Mg (L71) parent material a series of Al–Cu–Si alloys was employed in which the Cu content varied from 3 to 8%, Si from 0 to 20%, and Mg from 0·35 to 1·5%. The alloys used in tests 9 onward were prepared at a later stage when it became apparent that an alloy with about 3% Si would be the most suitable for resisting cracking.

For the DTD 5050 type plate material, Al–Zn–Mg alloys were used with the following ranges of composition: Zn, 2–9%; Mg, 1–5%; Cu, 0–1·5%; Si, 0·2–1·5%. Initially three types of filler alloy were investigated: high zinc–low magnesium (tests 15–18); medium zinc–medium magnesium (tests 19–22); low zinc–high magnesium (tests 23–26). Later in the programme additional alloys, some containing higher silicon, were investigated because of the possibility that the presence of silicon would give improved cracking resistance.

The Al–Zn–Mg alloy parent metal was typical of that widely used in the British aircraft industry. It had a higher total alloy content than the Al–Zn–Mg alloys, which are at present being used on the continent for welding purposes.

The composition of the various filler alloys and the parent materials are given in Tables I and II. Because the results have to be considered in terms of the weld-bead analysis, and not only the filler composition, these tables also give the corresponding weld-bead analysis, which has been estimated from dilution measurements.

RESULTS

All the weld beads examined responded in varying degrees to artificial ageing. Some compositions increased in hardness by more than 50%, the final maximum hardness being comparable with that of the unaffected parent material. Particularly good results in comparison with parent metal filler were obtained with some of the Al–Cu–Si filler alloys in weld beads aged artificially.

The results of the artificial ageing tests are summarized in Tables III and IV, which indicate the maximum hardness attained at the various ageing temperatures, and the time to reach this maximum. As would be expected, the lower ageing temperatures usually resulted in higher maximum hardness values, which were attained after longer ageing times. At the highest ageing temperature of 200°C. the Al–Cu–Si weld bead hardnesses rose to a maximum in less than one hour and, in general, further ageing caused only a slight drop in hardness. Ageing curves for the Al–Zn–Mg weld beads were generally of two types, a slowly rising curve and a curve with an inflexion between one and five hours, rising finally to a higher maximum hardness than the first type of curve. The latter type of stepped curve was associated particularly with high

zinc and low magnesium contents and also with the highest peak hardness values.

The Al–Cu–Si weld beads responded sluggishly to natural ageing, the maximum hardness being attained after about twelve weeks with little further change thereafter. The maximum hardness was generally 15–20 points D.P.N. below that when the same weld bead was aged artificially. With low magnesium or high silicon filler alloys, natural ageing was negligible.

The Al–Zn–Mg weld beads with high zinc–low magnesium gave the greatest hardness values after natural ageing, but this group and the medium zinc–medium magnesium group weld beads gave hardness values much below the maximum hardnesses reached after artificial ageing. The low zinc–high magnesium weld beads gave the lowest hardness values but here the increase in hardness after twelve weeks natural ageing was of the same order as that obtained by artificial ageing.

The addition of small amounts of silicon to the filler metal used for Al–Zn–Mg alloys was investigated because it was thought that such additions could be beneficial in regard to cracking. It was known that, although cracking resistance could be improved by welding DTD 5050 with an Al–5% Si filler, the weld properties were impaired by the formation of Mg_2Si.

Table I

Al–Cu–Si Weld Bead Compositions on L71 plate

Test No.	*Filler alloy*	*Filler alloy composition, %**					*Dilution, %*	*Weld composition, %†*			
		Zn	*Mg*	*Cu*	*Si*	*Ti*		*Zn*	*Mg*	*Cu*	*Si*
1	1	—	—	6·22	0·1	0·075	27	—	0·2	5·6	0·2
2	3A	—	1·02	5·92	1·45	0·10	28	—	0·9	5·4	1·3
3	3B	—	1·0	6·12	0·97	0·085	40	—	0·9	5·3	0·9
4	4A	—	1·46	5·98	1·95	0·07	36	—	1·2	5·3	1·5
5	4B	—	1·50	5·98	1·01	0·065	45	—	1·2	5·2	0·9
6	578	—	0·58	4·37	0·81	0·14	34	—	0·6	4·3	0·8
7	5% Si	—	—	—	5·1	—	46	—	0·3	2·0	3·4
8	10% Si	—	—	—	10·3	—	30	—	0·2	1·3	7·4
9	Cusil 420	—	—	3·04	20·45	—	30	—	0·2	3·4	14·5
10	Cusil 83	—	0·36	8·12	3·2	0·33	23	—	0·5	7·2	2·6
11	Cusil 73a	—	0·5	7·0	3·0	0·23	34	—	0·56	6·0	2·2
12	Cusil 73b	—	1·0	7·0	3·0	0·23	40	—	0·9	5·8	2·1
13	Cusil 73c	—	1·55	7·1	2·95	0·23	28·6	—	1·3	6·3	2·3

Parent metal analysis: 4·15% Cu, 0·72% Mg, 0·78% Si, 0·72% Mn, 0·41% Fe.
* By analysis. † Estimated from dilution.

Table II

Al–Cu–Si Weld Bead Compositions on DTD 5050 plate

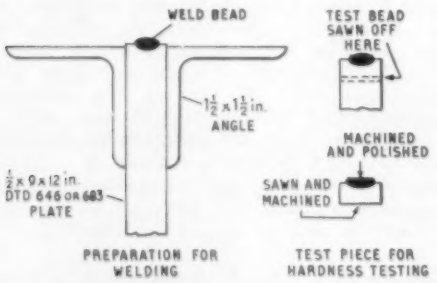
Test No.	*Filler alloy*	*Filler alloy composition, %**					*Dilution, %*	*Weld composition, %†*			
		Zn	*Mg*	*Cu*	*Si*	*Ti*		*Zn*	*Mg*	*Cu*	*Si*
15	a 545	9·07	1·1	—	—‡	0·14	38	7·9	1·75	0·2	0·2
16	a 546	8·97	1·2	0·47	—	0·14	62	7·2	2·2	0·5	0·2
17	a 547	7·80	2·07	—	—	0·15	53	6·9	2·4	0·3	0·2
18	a 548	7·60	2·05	0·53	—	0·13	55	6·7	2·45	0·5	0·2
19	b 552	5·55	3·05	1·5	—	0·15	51	5·8	2·9	1·0	0·2
20	b 553	5·57	2·97	0·52	—	0·15	64	5·9	2·8	0·5	0·2
21	b 593	5·25	3·0	—	—	0·14	54	5·7	2·9	0·3	0·2
22	b 554	6·55	2·95	0·48	—	0·14	56	6·25	2·8	0·5	0·2
23	c 555	4·49	3·98	—	—	0·14	58	5·35	3·3	0·3	0·2
24	c 556	4·75	3·85	0·48	—	0·14	56	5·5	3·25	0·5	0·2
25	c 557	4·45	5·36	—	—	0·14	34	5·0	4·5	0·2	0·2
26	c 558	4·44	5·49	0·49	—	0·12	48	5·2	4·2	0·5	0·2
27	579	6·10	2·64	1·35	0·14	0·14	53	6·05	2·70	0·9	0·2
28	Zimag 26a	1·8	5·8	0·34	0·2	0·12	53	4·0	4·2	0·4	0·2
29	Zimag 26b	3·0	5·8	0·19	—	0·58	44	4·3	4·5	0·3	0·2
30	Zimag 46	4·0	5·7	0·34	0·2	0·1	50	5·0	4·2	0·4	0·2
31	Zimagsil 43a	4·4	3·65	—	0·6	0·24	51	5·2	3·2	0·2	0·4
32	Zimagsil 43b	4·26	3·45	—	1·54	0·22	63	5·4	3·0	0·3	0·73
33	Zimagsil 71	7·97	1·46	—	0·97	0·29	45	7·1	2·0	0·2	0·56

Parent metal analysis: 6·03% Zn, 2·76% Mg, 0·51% Cu, 0·32% Mn, 0·20% Si, 0·27% Fe, 0·1% Ti.
* By analysis. † Estimated from dilution. ‡ Si to a nominal 0·15–0·20% in each alloy.

metals, has been investigated by hardness testing weld beads laid on solid plate, since the testing of actual welds would have been too costly in time and material. With several filler materials the 'as-deposited' weld metal, suitably aged, reached a hardness approximating that of the unaffected parent metal. This could be of considerable importance in practice, because although large welded structures cannot generally be solution heat treated, there are many applications where artificial ageing after welding could be practicable. The possibility of welding material in the solution heat-treated condition and ageing the whole welded assembly appears to be promising. It is emphasized that ageing behaviour is only one property of weld metal which must be considered when investigating the suitability of an alloy for use as a filler metal.

EXPERIMENTAL PROCEDURE

Because of the large number of filler alloys for investigation, it was necessary to use a simple and economical method of depositing the weld metal. This had to give dilution and thermal conditions comparable with those existing in practice. To avoid the preparation of plate edges, bead-on-plate deposits were made, but it was naturally impossible to lay more than a single bead on each piece of plate, because the heat


WELD BEAD
TEST BEAD SAWN OFF HERE
1½ x 1½ in. ANGLE
MACHINED AND POLISHED
½ x 9 x 12 in. DTD 646 OR 683 PLATE
SAWN AND MACHINED
PREPARATION FOR WELDING
TEST PIECE FOR HARDNESS TESTING

1—Preparation of samples for ageing tests

from the second bead would affect the first. The method adopted was to lay a bead along the edge of ½ in. thick plate, held vertically as shown in Fig. 1. After welding and allowing the plate to cool, the weld bead was cut off, exposing a fresh edge for the next weld bead.

Weld beads were deposited on either L71 or DTD 5050 plate according to the type of filler alloy, using a standard argon-arc torch with a $\frac{5}{32}$ in. dia., plain tungsten electrode and a current of 160 amp. Steel angles on each side of the test plate provided backing for the argon shield. The filler rod was 10 s.w.g. The dilution was measured from microsections and varied between about 30 and 55%, thus covering the range likely to be encountered in fillet welds and prepared butt welds. As some difficulty was experienced in obtaining consistent dilution values an estimate of the weld bead composition was made in each test.

A 3 in. long piece was cut from each 12 in. machined and polished weld-bead sample for natural ageing tests. The remainder of each sample was cut into ½ in. long pieces for artificial ageing tests, which were carried out for various times at temperatures within the range normally specified for the parent metal, that is, 160–200°C. for L71 and 110–140°C. for DTD 5050.

All the results reported are the average of five hardness impressions.

MATERIALS

With the Al–Cu–Mg (L71) parent material a series of Al–Cu–Si alloys was employed in which the Cu content varied from 3 to 8%, Si from 0 to 20%, and Mg from 0·35 to 1·5%. The alloys used in tests 9 onward were prepared at a later stage when it became apparent that an alloy with about 3% Si would be the most suitable for resisting cracking.

For the DTD 5050 type plate material, Al–Zn–Mg alloys were used with the following ranges of composition: Zn, 2–9%; Mg, 1–5%; Cu, 0–1·5%; Si, 0·2–1·5%. Initially three types of filler alloy were investigated: high zinc–low magnesium (tests 15–18); medium zinc–medium magnesium (tests 19–22); low zinc–high magnesium (tests 23–26). Later in the programme additional alloys, some containing higher silicon, were investigated because of the possibility that the presence of silicon would give improved cracking resistance.

The Al–Zn–Mg alloy parent metal was typical of that widely used in the British aircraft industry. It had a higher total alloy content than the Al–Zn–Mg alloys, which are at present being used on the continent for welding purposes.

The composition of the various filler alloys and the parent materials are given in Tables I and II. Because the results have to be considered in terms of the weld-bead analysis, and not only the filler composition, these tables also give the corresponding weld-bead analysis, which has been estimated from dilution measurements.

RESULTS

All the weld beads examined responded in varying degrees to artificial ageing. Some compositions increased in hardness by more than 50%, the final maximum hardness being comparable with that of the unaffected parent material. Particularly good results in comparison with parent metal filler were obtained with some of the Al–Cu–Si filler alloys in weld beads aged artificially.

The results of the artificial ageing tests are summarized in Tables III and IV, which indicate the maximum hardness attained at the various ageing temperatures, and the time to reach this maximum. As would be expected, the lower ageing temperatures usually resulted in higher maximum hardness values, which were attained after longer ageing times. At the highest ageing temperature of 200°C. the Al–Cu–Si weld bead hardnesses rose to a maximum in less than one hour and, in general, further ageing caused only a slight drop in hardness. Ageing curves for the Al–Zn–Mg weld beads were generally of two types, a slowly rising curve and a curve with an inflexion between one and five hours, rising finally to a higher maximum hardness than the first type of curve. The latter type of stepped curve was associated particularly with high

zinc and low magnesium contents and also with the highest peak hardness values.

The Al–Cu–Si weld beads responded sluggishly to natural ageing, the maximum hardness being attained after about twelve weeks with little further change thereafter. The maximum hardness was generally 15–20 points D.P.N. below that when the same weld bead was aged artificially. With low magnesium or high silicon filler alloys, natural ageing was negligible.

The Al–Zn–Mg weld beads with high zinc–low magnesium gave the greatest hardness values after natural ageing, but this group and the medium zinc–medium magnesium group weld beads gave hardness values much below the maximum hardnesses reached after artificial ageing. The low zinc–high magnesium weld beads gave the lowest hardness values but here the increase in hardness after twelve weeks natural ageing was of the same order as that obtained by artificial ageing.

The addition of small amounts of silicon to the filler metal used for Al–Zn–Mg alloys was investigated because it was thought that such additions could be beneficial in regard to cracking. It was known that, although cracking resistance could be improved by welding DTD 5050 with an Al–5% Si filler, the weld properties were impaired by the formation of Mg_2Si.

Table I

Al–Cu–Si Weld Bead Compositions on L71 plate

Test No.	*Filler alloy*	*Filler alloy composition, %**					*Dilution, %*	*Weld composition, %†*			
		Zn	*Mg*	*Cu*	*Si*	*Ti*		*Zn*	*Mg*	*Cu*	*Si*
1	1	—	—	6·22	0·1	0·075	27	—	0·2	5·6	0·2
2	3A	—	1·02	5·92	1·45	0·10	28	—	0·9	5·4	1·3
3	3B	—	1·0	6·12	0·97	0·085	40	—	0·9	5·3	0·9
4	4A	—	1·46	5·98	1·95	0·07	36	—	1·2	5·3	1·5
5	4B	—	1·50	5·98	1·01	0·065	45	—	1·2	5·2	0·9
6	578	—	0·58	4·37	0·81	0·14	34	—	0·6	4·3	0·8
7	5% Si	—	—	—	5·1	—	46	—	0·3	2·0	3·4
8	10% Si	—	—	—	10·3	—	30	—	0·2	1·3	7·4
9	Cusil 420	—	—	3·04	20·45	—	30	—	0·2	3·4	14·5
10	Cusil 83	—	0·36	8·12	3·2	0·33	23	—	0·5	7·2	2·6
11	Cusil 73a	—	0·5	7·0	3·0	0·23	34	—	0·56	6·0	2·2
12	Cusil 73b	—	1·0	7·0	3·0	0·23	40	—	0·9	5·8	2·1
13	Cusil 73c	—	1·55	7·1	2·95	0·23	28·6	—	1·3	6·3	2·3

Parent metal analysis: 4·15% Cu, 0·72% Mg, 0·78% Si, 0·72% Mn, 0·41% Fe.
* By analysis. † Estimated from dilution.

Table II

Al–Cu–Si Weld Bead Compositions on DTD 5050 plate

Test No.	*Filler alloy*	*Filler alloy composition, %**					*Dilution, %*	*Weld composition, %†*			
		Zn	*Mg*	*Cu*	*Si*	*Ti*		*Zn*	*Mg*	*Cu*	*Si*
15	a 545	9·07	1·1	—	—‡	0·14	38	7·9	1·75	0·2	0·2
16	a 546	8·97	1·2	0·47	—	0·14	62	7·2	2·2	0·5	0·2
17	a 547	7·80	2·07	—	—	0·15	53	6·9	2·4	0·3	0·2
18	a 548	7·60	2·05	0·53	—	0·13	55	6·7	2·45	0·5	0·2
19	b 552	5·55	3·05	1·5	—	0·15	51	5·8	2·9	1·0	0·2
20	b 553	5·57	2·97	0·52	—	0·15	64	5·9	2·8	0·5	0·2
21	b 593	5·25	3·0	—	—	0·14	54	5·7	2·9	0·3	0·2
22	b 554	6·55	2·95	0·48	—	0·14	56	6·25	2·8	0·5	0·2
23	c 555	4·49	3·98	—	—	0·14	58	5·35	3·3	0·3	0·2
24	c 556	4·75	3·85	0·48	—	0·14	56	5·5	3·25	0·5	0·2
25	c 557	4·45	5·36	—	—	0·14	34	5·0	4·5	0·2	0·2
26	c 558	4·44	5·49	0·49	—	0·12	48	5·2	4·2	0·5	0·2
27	579	6·10	2·64	1·35	0·14	0·14	53	6·05	2·70	0·9	0·2
28	Zimag 26a	1·8	5·8	0·34	0·2	0·12	53	4·0	4·2	0·4	0·2
29	Zimag 26b	3·0	5·8	0·19	—	0·58	44	4·3	4·5	0·3	0·2
30	Zimag 46	4·0	5·7	0·34	0·2	0·1	50	5·0	4·2	0·4	0·2
31	Zimagsil 43a	4·4	3·65	—	0·6	0·24	51	5·2	3·2	0·2	0·4
32	Zimagsil 43b	4·26	3·45	—	1·54	0·22	63	5·4	3·0	0·3	0·73
33	Zimagsil 71	7·97	1·46	—	0·97	0·29	45	7·1	2·0	0·2	0·56

Parent metal analysis: 6·03% Zn, 2·76% Mg, 0·51% Cu, 0·32% Mn, 0·20% Si, 0·27% Fe, 0·1% Ti.
* By analysis. † Estimated from dilution. ‡ Si to a nominal 0·15–0·20% in each alloy.

In an attempt to find a suitable compromise, smaller additions of silicon were made, and these appeared to have little effect on the maximum hardness attained, except with an alloy high in zinc and low in magnesium. Here, 0·6% Si in the weld bead reduced the maximum hardness by about 10 points D.P.N.

Tables V and VI summarize the data on artificial ageing. Representative examples of the various ageing curves are presented in Figs. 2–8.

DISCUSSION

Al–Cu–Si Weld Beads

With L71 parent material the special filler alloy 4A (test 4) gave a maximum hardness value after artificial ageing well above that obtained with any other filler. The hardness was above that for the parent metal filler by approximately 25 points D.P.N. and above that for the Al–5% Cu filler by over 40 points D.P.N. (Fig. 2*a*). It is evident that this superiority was due largely to the higher Mg content of filler 4A. The effect of variations in Mg content alone is shown in Fig. 2*b* in which filler alloys 4B and 3B are compared. As shown in Table I, the weld bead deposited from filler 4B contained 0·3% higher Mg than that from filler 3B but otherwise the composition was the same. At all ageing times, at either 175 or 200°C., the higher magnesium content gave a hardness higher by about 10 points D.P.N.

Silicon also tended to increase the hardness though to a smaller extent than magnesium, as indicated in Fig. 2*c*. The hardness was greater when filler 3A was used because the Si content was 0·4% higher than in the 3B weld bead.

Table III
Artificial Ageing of Al–Cu–Si Weld Beads

Test No.	*Filler alloy*	*Ageing time for max. hardness, hr.*				*Max. hardness after ageing, D.P.N.*				*Hardness after ageing at 200°C., D.P.N.*	
		200°	*190°*	*175°*	*160°*	*200°*	*190°*	*175°*	*160°*	*2 hr.*	*10 hr.*
1	1	8	11	11	16	94	95	101	100	87	—
2	3A	½	5	8	22	126	136	139	140	126	126
3	3B	1	10	11	22	122	126	129	135	121	122
4	4A	½	4	10	22	135	136	144	148	130	130
5	4B	½	6	11	22	131	138	138	141	131	—
6	578	½	11	11	17	102	115	120	123	102	—
7	5% Si	½	4	16	16	81	89	96	97	74	71
8	10% Si	½	3	11	16	95	102	120	113	86	83
9	Cusil 420	—	—	—	—	140	140	140	140	140	140
10	Cusil 83	2	5	16	22	127	124	125	129	127	114
11	Cusil 73a	3	—	—	37	111	—	—	122	110	102
12	Cusil 73b	3	—	—	37	140	—	—	151	138	135
13	Cusil 73c	2	—	—	37	146	—	—	156	146	120

Table IV
Artificial Ageing of Al–Zn–Mg Weld Beads

Test No.	*Filler alloy*	*Ageing time for max. hardness, hr.*				*Max. hardness after ageing, D.P.N.*				*Hardness after ageing at 140°C., D.P.N.*	
		140°	*130°*	*120°*	*110°*	*140°*	*130°*	*120°*	*110°*	*2 hr.*	*10 hr*
15	a 545	11	16	40	—	145	146	159	—	122	144
16	a 546	11	16	55	70	152	157	165	169	126	149
17	a 547	11	22	55	70	156	159	166	164	124	152
18	a 548	16	22	55	70	150	159	159	168	118	149
19	b 552	16	16	40	55	141	143	150	158	107	136
20	b 553	22	22	55	70	141	141	152	157	110	133
21	b 593	16	16	—	100	138	140	—	150	107	134
22	b 554	9	22	30	70	146	151	155	161	115	146
23	c 555	22	12	55	55	133	139	151	152	105	124
24	c 556	16	16	55	70	138	143	149	152	105	136
25	c 557	16	22	55	55	139	143	143	144	106	132
26	c 558	16	16	55	55	131	132	149	149	105	128
27	579	5	22	50	—	138	151	151	—	122	129
28	Zimag 26a	11	—	—	—	126	—	—	—	103	125
29	Zimag 26b	11	—	—	—	136	—	—	—	105	135
30	Zimag 46	11	—	—	—	135	—	—	—	114	133
31	Zimagsil 43a	11	—	—	—	129	—	—	—	113	127
32	Zimagsil 43b	16	—	—	—	133	—	—	—	115	129
33	Zimagsil 71	22	—	—	—	141	—	—	—	112	128

Table V
Natural Ageing of Al–Cu–Si Weld Beads

Test No.	*Filler alloy*	*Hardness after 12 weeks, D.P.N.*	*Hardness after 24 weeks, D.P.N.*	*Max. hardness after ageing at 200°C. (for comparison), D.P.N.*
1	1	82	82	94
2	3A	112	112	126
3	3B	111	112	122
4	4A	117	117	135
5	4B	115	115	131
6	578	99	100	102
7	5% Si	71	71	81
8	10% Si	81	81	95
9	Cusil 420	140	140	140
10	Cusil 83	117	117	124
11	Cusil 73a	112	112	111
12	Cusil 73b	126	127	140
13	Cusil 73c	133	133	146

Table VI
Natural Ageing of Al–Zn–Mg Weld Beads

Test No.		*Filler alloy*	*Hardness after 12 weeks, D.P.N.*	*Hardness after 24 weeks, D.P.N.*	*Max. hardness after ageing at 140°C. (for comparison), D.P.N.*
15	a	545	130	131	145
16		546	131	136	152
17		547	129	129	156
18		548	128	128	150
19	b	552	124	125	141
20		553	124	124	141
21		593	120	123	138
22		554	127	127	146
23	c	555	121	121	133
24		556	129	129	138
25		557	121	121	139
26		558	125	127	131
27		579	130	132	138
28		Zimag 26a	115	—	126
29		Zimag 26b	125	—	136
30		Zimag 46	130	—	135
31		Zimagsil 43a	125	—	129
32		Zimagsil 43b	120	—	133
33		Zimagsil 71	126	—	141

The effect of silicon on hardness is further illustrated in Fig. 2*d*. With a 5% Si filler, giving only 3·1% in the weld, as shown in Table I, low hardness was obtained and over-ageing was rapid. The hardness maxima obtained at the various temperatures were widely spaced. Similar curves, but approximately 10 points D.P.N. higher, were obtained when the Si in the weld was raised to 7·2% by using an Al–10% Si filler. When using a filler with an exceptionally high Si content, such as Cusil 420, a high hardness was obtained which was unaffected by ageing, although both Cu and Mg were present in the weld.

Figure 2*e* shows the ageing curve for Cusil 83 (test 10), one of the 3% Si alloys found to give very satisfactory crack resistance. The weld bead produced had a high initial hardness but ageing was sluggish and there was not a proportionate increase in hardness

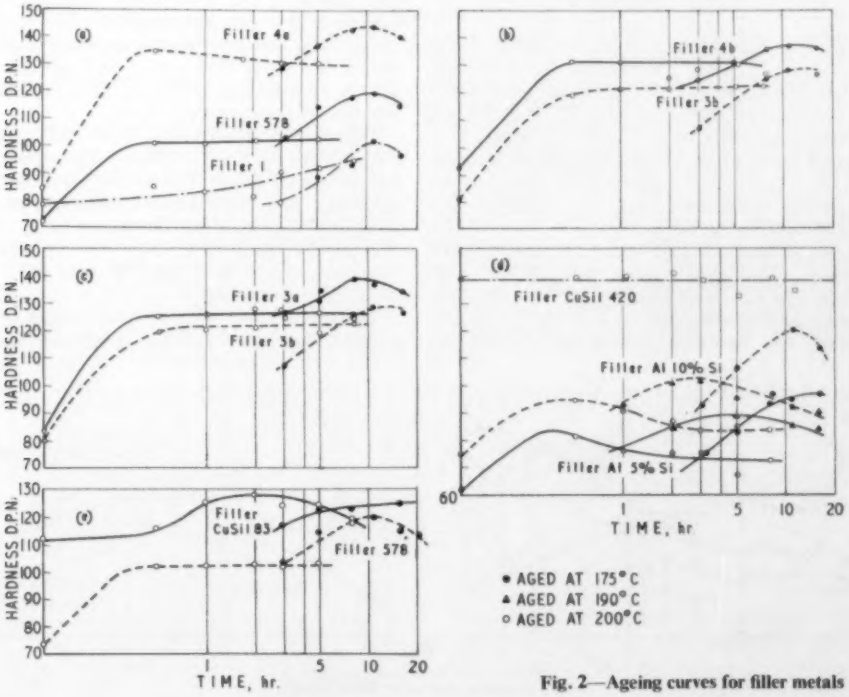
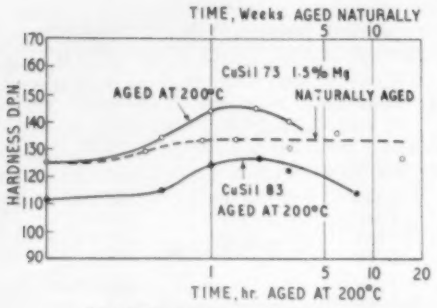
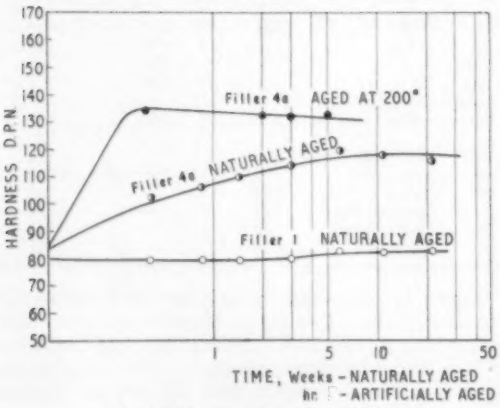


Fig. 2—Ageing curves for filler metals



3—Ageing curves for filler metals


HARDNESS D.P.N.
Filler 4a AGED AT 200°
Filler 4a NATURALLY AGED
Filler 1 NATURALLY AGED
TIME, Weeks - NATURALLY AGED
hr - ARTIFICIALLY AGED

4—Ageing curves for filler metals

after ageing. This was thought to be due partly to the low dilution with this filler but mainly because of the relatively low Mg content. Later in the programme of tests three alloys were prepared with 7% Cu, 3% Si, and magnesium contents of 0·5%, 1·0%, and 1·5%. (These fillers proved to be extremely fluid on welding and, with the experimental procedure adopted, the required dilution in the weld bead was obtained only with the filler containing 1·5% Mg).

Cusil 73 containing 1·5% Mg (test 13) gave a maximum hardness value after ageing well above those obtained with any previous filler except No. 4A. The natural ageing of this alloy and of Cusil 83 proved to be very poor, the hardness increasing by only 10 D.P.N. after ten weeks ageing. Figure 3 shows the ageing curves for these fillers to be very much the same, and it is evident from this and previous work that the superiority of the Cusil 73 filler results largely from its higher Mg content.

As would be expected, the Mg content of the Al–Cu–Mg weld beads is the major factor determining the response to natural ageing, as shown by the better ageing characteristics of weld beads from filler 4A compared with filler No. 1 (see Fig. 4). The weld beads made from the filler alloys other than 3A, 3B, 4A, and 4B have little susceptibility to natural ageing.

Al–Zn–Mg Weld Beads

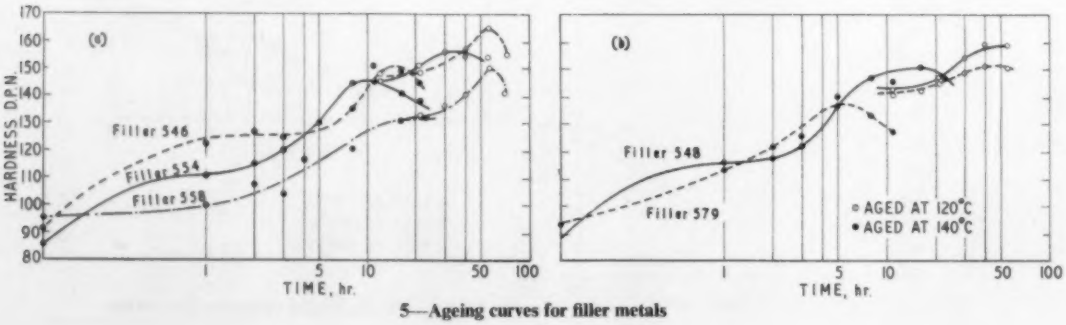
The highest hardness values in weld beads deposited on DTD 5050 parent material were obtained with filler alloys high in zinc and low in magnesium. It appears that the hardness of the weld bead is determined by the amount of these elements, copper having a small and uncertain effect except if present at about 1% when a slight increase in the maximum hardness is noted.

Ignoring copper content the results can be divided into three categories: (*a*) high zinc–low magnesium with a nominal weld bead analysis of 7% Zn, 2% Mg, which includes all weld beads having a hardness of over 118 after two hours ageing at 140°C.; (b) medium zinc–medium magnesium, with a nominal weld bead analysis of 6% Zn, 3% Mg giving hardnesses of 107–115 after two hours; and (*c*) low zinc–high magnesium, with a nominal weld bead analysis of 5% Zn, 4% Mg giving hardnesses of 105–106 after two hours.

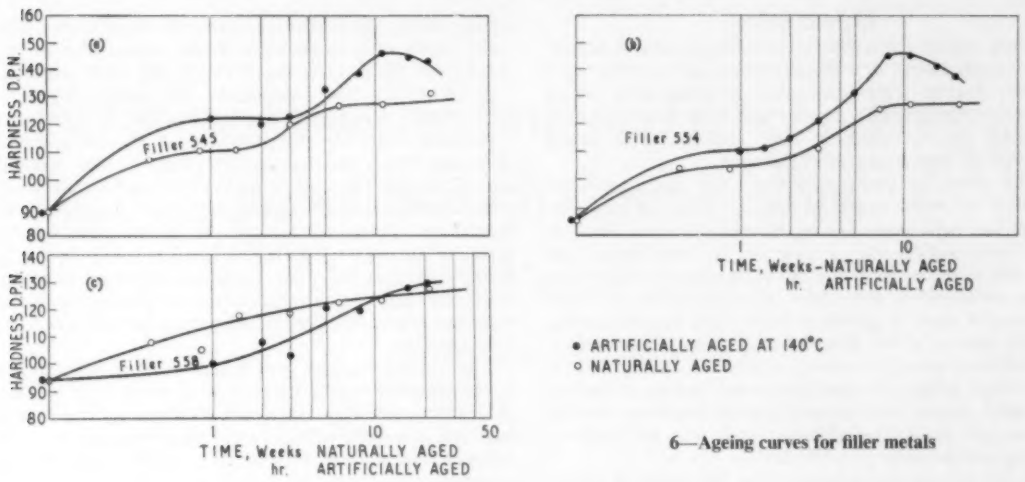
Representative ageing curves from each of these groups are shown in Fig. 5*a*, results for the whole series being summarized in Table VI. Raising the Mg and lowering the Zn content reduced the maximum hardness and also appeared to affect the form of the curve. The low zinc–high magnesium weld bead, produced by filler 558 (test 26), age-hardened more slowly and did not show any sharp change in hardening rate at short ageing times.

Figure 5*b* compares the best results obtained from any of the Al–Cu–Si special fillers with those from parent metal filler. On ageing at 140°C., alloy 548 (test 18) gave a maximum hardness of 150 D.P.N. after ten hours. After five hours both alloy 548 and the parent metal filler 579 (test 27) had the same hardness of 137, and the 579 weld bead was then at maximum hardness.

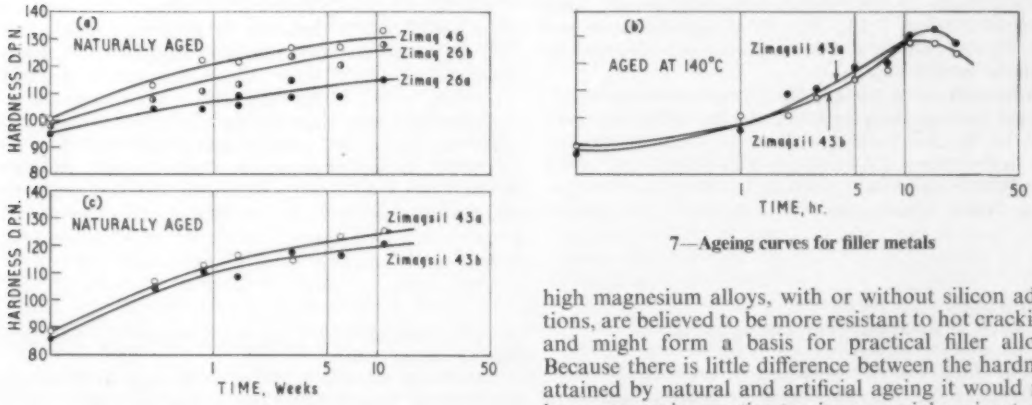
Natural ageing with all the Al–Zn–Mg fillers was sluggish but since maxima were not reached in the



5—Ageing curves for filler metals



6—Ageing curves for filler metals

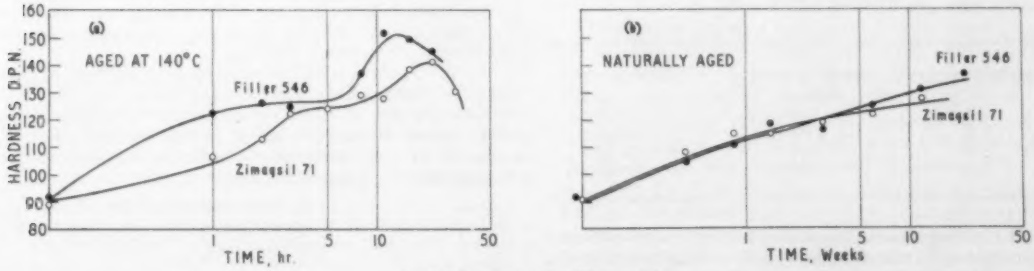


7—Ageing curves for filler metals

tests there is evidence that prolonged ageing could give a significant improvement in properties. The hardness attained with the high-zinc filler, even after 24 weeks ageing, was substantially below that resulting from artificial ageing. Natural and artificial ageing curves for high, medium, and low-zinc filler alloys are shown in Figs. 6*a*, *b*, and *c* respectively.

Although the low zinc–high magnesium alloys did not give such high weld hardnesses as the higher zinc alloys, there was less difference between the results obtained by artificial and natural ageing. Low zinc–high magnesium alloys, with or without silicon additions, are believed to be more resistant to hot cracking, and might form a basis for practical filler alloys. Because there is little difference between the hardness attained by natural and artificial ageing it would not be necessary in practice to give a special ageing treatment after welding. Tests 28–32 and Figs. 7*a*, *b* and *c* show the behaviour of alloys of this type.

Figures 7*b* and *c* show that the addition of Si to weld beads with low zinc–high magnesium contents appeared to have little effect on the maximum hardness attained after ageing. With the high zinc–low magnesium alloys however (Fig. 8), an addition of 0·6% Si to the weld bead decreased the maximum hardness by approximately 10 D.P.N. after artificial ageing and indicated a similar tendency with natural ageing.



8—Ageing curves for filler metals

CONCLUSIONS

Weld metal from the high-strength heat-treatable aluminium alloys can be hardened appreciably by a simple ageing treatment after welding and, where excessive softening in the heat-affected zone has been avoided during welding, this should be a useful method of improving joint strength.

The effect of composition on the ageing characteristics of weld beads deposited from 33 different fillers has been examined by hardness testing. Because this examination was specific to the weld bead, and did not involve the whole joint, a clearer picture has been obtained of the effect of composition on weld properties than in previous work with tensile testing, where failure in the heat-affected zone often masked the effect of changes in the properties of the weld bead. Now that more is known about the ageing properties of weld metal further mechanical tests on welded joints can be carried out to study the influence of ageing on the joint as a whole.

In Al–Cu–Si weld beads, the Mg content has a marked effect on hardness after ageing. With a filler alloy containing 1·5% Mg, weld hardnesses above that for the fully heat-treated plate were obtained by artificial ageing only.

Although some of the alloys responded slightly to natural ageing, the maximum reached after 24 weeks was 15–20 D.P.N. lower than for artificial ageing. The high-copper, 3% Si alloys, which have been found particularly suitable in resisting cracking, do not give weld beads which respond appreciably to natural ageing. With Mg additions, however, these alloys give weld beads with hardnesses of the same order as the unaffected plate, when aged artificially after welding.

With Al–Zn–Mg weld beads, the maximum hardness obtained by ageing decreases as the Zn content is lowered and the Mg content is raised. Similar changes in composition have a smaller effect on the natural ageing properties and with the low zinc–high magnesium alloys natural ageing, although sluggish, gave hardnesses almost equivalent to those obtained by artificial ageing at 140°C. The addition of up to 1·5% Si to this type of filler alloy to improve cracking resistance had only a minor effect on the ageing of the weld bead, and this type of alloy may be worth further investigation.

The results suggest that when welding Al–Cu–Mg (L71) alloys it would be profitable to age the welded assembly artificially. To avoid over-ageing the parent material it would probably be an advantage to weld solution heat-treated and not fully heat-treated material.

There is a possibility of developing filler alloys for Al–Zn–Mg parent material to give weld beads that will age satisfactorily, though sluggishly, at room temperature. With these alloys the parent material would be welded in the fully heat-treated condition.

Although some of the ageing effects observed are not unusual, in that they are consistent with the behaviour of solution-treated wrought material, it is perhaps remarkable that 'as-deposited' cast weld metal should respond so effectively to a simple ageing treatment.

LETTER TO THE EDITOR

Brazing Magnesium and its Alloys

A method has been developed for brazing magnesium and its alloys using zinc as the brazing material.

The authors were specifically interested in a special alloy made for them by Messrs. Magnesium Elektron Ltd., in which 10% Cd was added to alloy ZW6, with a composition: Zn, 5·5%, Zr, 0·7%, Mg to 100%. However the brazing of pure magnesium was also studied.

The surfaces to be bonded were thoroughly cleaned, and a 0·002 in. thick sheet of zinc was then sandwiched between them at reasonable pressure. The metal was heated to 400°C. either in vacuum or in a dry hydrogen atmosphere, and was held at this temperature for a certain length of time (called the 'brazing time' in the table that follows). The zinc was seen to form a molten alloy with the main mass of metal at about 390°C. The table gives bond strengths obtained with small tensile-test samples.

Brazing time, min.	*Breaking Stress, lb/sq.in*	*Atmosphere*
120	17500	in vacuum
120	15000	in hydrogen
10	14920	in hydrogen
5	15000	in hydrogen

With these small samples similar strengths were obtained in hydrogen and in vacuum. For joints of large area vacuum brazing is preferable, for the risk of trapping air in the joint is reduced. The joints are substantially free from pitting and corrosion.

The brazed alloy lost little or no strength as a result of the heat treatment received during brazing. The U.T.S. of an untreated sample equalled 21·7 tons/sq.in., that of a sample which had been held at 400°C. for 1 hr. equalled 20·9 tons/sq.in.

When pure magnesium was brazed in the above manner, weak joints with a breaking stress of about 2000 lb./sq.in. were obtained. But if two equally thick sheets, one of zinc and one of cadmium, were sandwiched between the surfaces to be joined it was possible to obtain a breaking stress of 7000 lb./sq.in. at a brazing temperature of 360°C.

This brazing technique has been used in the fabrication of high-speed rotors made either of pure magnesium or the special alloy. The rotors were 10 in. dia. and were made in two halves brazed together along a plane perpendicular to the axis of rotation. Speeds of 36,000 r.p.m. were achieved before braze failure. Because of the complicated shape of the rotors it is very difficult to calculate the forces acting on the braze under these conditions.

The described method of brazing is of interest in that joints of good quality and strength have been obtained without the use of corrosive fluxes and at temperatures safely below the melting point of the bonded metal. It seems likely that the method could be adapted to the brazing of other magnesium alloys.

I. Butterworth, B.Sc., Ph.D.
P. A. Egelstaff, B.Sc., Ph.D.
L. V. Lewis.
Atomic Energy Research Establishment, Harwell.

Pulsating Pressure Fatigue Tests on Pressure Vessel Branch Connections

By P. H. R. Lane, B.Sc., A.I.M.

SYNOPSIS

THE paper describes a limited investigation of the behaviour of model pressure vessels (20 inches (510 mm) diameter, 1 inch (25·4 mm) thick) subjected to pulsating internal pressure. Each vessel was provided with one branch and the object of the tests was to compare four different welding details used for attaching the branches to the shells. Two of the joint details had interpenetrating welds made from the inside and outside of the shell, and two had inner and outer welds which did not fully penetrate the shell thickness. Examination of the fractures showed that the root area of the welds in the latter designs was not a source of weakness.

Introduction

MANY different types of weld detail are employed for the attachment of branches to fusion-welded mild-steel pressure vessels. Details involving two interpenetrating welds, occupying the full thickness of the shell plate, are necessarily more expensive to produce than details with lighter welds, but some authorities have considered their use essential. Some users have for a number of years employed weld details in which no attempt is made to obtain inter-penetration, leaving an annular space between the shell plate and the branch. Since such systems are economically attractive, the tests described in this report have been designed to give some information on the relative strengths of the two types of detail. It should be noted that only a limited number of tests has been undertaken, and that the shell stress at the test pressure was rather higher than is usual in service. Accordingly, the tests provide only a comparison between the details examined, and the number of cycles sustained by each design cannot be related to their expected service life.

An evaluation of full- and partial-penetration welds in this way has not previously been carried out, the majority of tests on pressure vessels having been of the bursting type consisting of one application only of pressure. The fatigue method was used in some tests carried out in 1938 for the Institution of Mechanical Engineers,[1] but the interest in these tests was centred on the behaviour of the welded seams of the vessels and not the branch connections. One failure did occur at a reinforced branch connection. The branch was $2\frac{1}{2}$ in. bore and was attached with a compensating plate to a vessel 54 in. outside dia. $\times 1\frac{1}{4}$ in. thick. Failure occurred after 56,000 cycles of pressure at a maximum limit of 1100 lb/in², which would produce a mean shell hoop stress of approximately 10 tons/in². The branch was allowed to protrude inside the vessel, but drainage slots in the protruding portion, and the presence of the compensating plate, make it difficult to compare this result with those given in this report. It is encouraging to see, however, that with a similar stress level the life was of the same order as those found in the present tests.

The tests described in this paper were carried out on model vessels, the size of which was the result of a compromise between two conflicting factors. In order that the speed of testing might be as high as possible, it was necessary to use vessels with a small internal volume. It was not, however, feasible to use vessels of extremely small size, since it would not then be practicable to lay down welds which would be reasonably similar to those produced on full-scale vessels. The size chosen for the test vessels was thought to be the smallest which would enable welds to be made comparable with commercial practice. Only one branch was attached to each shell, since the first failure rendered the specimen useless for further testing. It was not, therefore, possible to economize in testing time by attaching more than one branch to each vessel.

TEST SPECIMENS

The test specimens consisted of mild-steel cylinders 20 in. bore and 1 in. thick; the length of the cylinders varied between 18 in. and 36 in. Each shell had one branch consisting of seamless pipe $6\frac{7}{8}$ in. bore $\times \frac{3}{8}$ in. thick welded in, using one of the four types of weld detail shown in Fig. 1. It will be seen that two of the details are for branches flush on the inside of the shell, and two for branches which protrude. In each case, one of the details has complete inter-penetration of welds made from inside and outside, while the other consists of two independent welds. The ends of the vessels were closed with 2:1 semi-ellipsoidal heads 1 in.

Paper presented at the Public Session of the Vienna Assembly of the International Institute of Welding, June 1958. Mr. Lane is Deputy Chief Metallurgist at the British Welding Research Association.

Table I

Static Mechanical Properties of Materials used for Shells and Branches

Property	*Shells*	*Branches*
Yield point, tons/in²	16	23
Ultimate tensile strength, tons/in²	26	35
Reduction of area, %	63	61
Elongation, % (on $4\sqrt{A}$)	40	38

thick, and the branches were closed with steel hemispheres $\frac{3}{8}$ in. thick. These types of end closure were chosen as being the best from the point of view of pulsating-pressure strength and of availability. Flat plates could not have been used successfully since, as has been shown previously,[2] the joints between the plate and the cylinder are subjected to high stresses which cause premature failure under fatigue conditions. While hemispherical ends might have been desirable for the vessels themselves, these were not readily procurable. In any case, no failures were experienced in the ellipsoidal ends. The pressure connection was made through the branch closure.

The length of the branch between the outside of the shell and the end closure was 4 in., which is considerably greater than the length of branch which can be considered as effective from the point of view of reinforcing the opening. This effective length is determined from the theory for a beam on an elastic foundation subjected to a terminal load and moment. The expressions for the stresses have a wave form with a rapidly diminishing amplitude;[3] the period of the wave is given by $\sqrt{(rt)}/n$, where r and t are the mean radius and thickness of the branch, and $n^4=3\,(1-\mu^2)$ where μ is Poisson's ratio. The static mechanical properties of the materials of the shells and the branches are given in Table I.

The welds attaching the branches to the shells were made with electrodes to Class E. 317 (BS.1719:1951) which had been carefully dried before use. The ends of the vessels were attached by submerged-arc welding. Extreme care was taken with the root runs of these welds, in order to avoid any possibility of their failing prematurely. In fact no failure occurred at the circumferential end welds. The shapes of the weld preparations and the profiles of the final welds were checked with templates at sixteen positions round the branch circumference. The welds were not dressed. Photomacrographs of sections of the welds are shown in Fig. 2.

After manufacture, but before the attachment of the branch end closure, the specimens were subjected to a stress-relieving treatment consisting of heating to approximately 600°C. in a gas-fired furnace, maintaining this temperature for one hour, and then allowing to cool in the furnace.

Table II

Pulsating Pressure Tests on Pressure Vessel Branch Connections

Test limits: Max pressure 2000 lb/in²
Min pressure 100 lb/in²

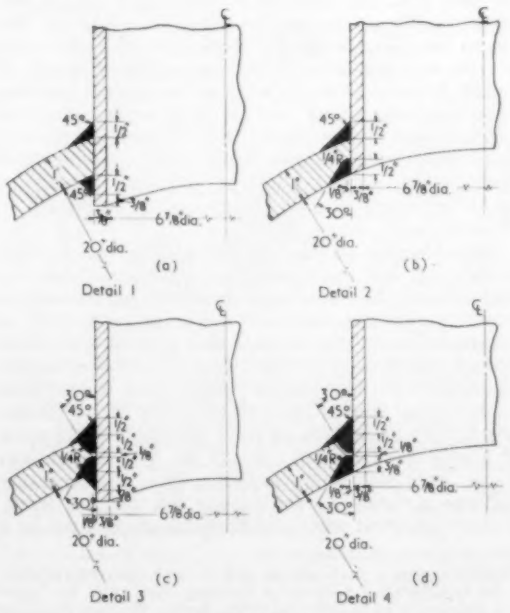
Mean shell hoop stress at max pressure 9·1 tons/in²

Specimen No.	*Design (see Fig. 1)*	*Branch*	*Weld Penetration*	*Life, Thousands of Cycles*
1	1			51·2
9	1	Protruding	Partial	54·8
10	1			114·0
2	2			33·3
7	2	Flush	Partial	32·8
8	2			40·8
4	3			136·8
11	3	Protruding	Complete	180·7
12	3			203·1
3	4			23·4
5	4	Flush	Complete	56·0
6	4			75·7

METHOD OF TEST

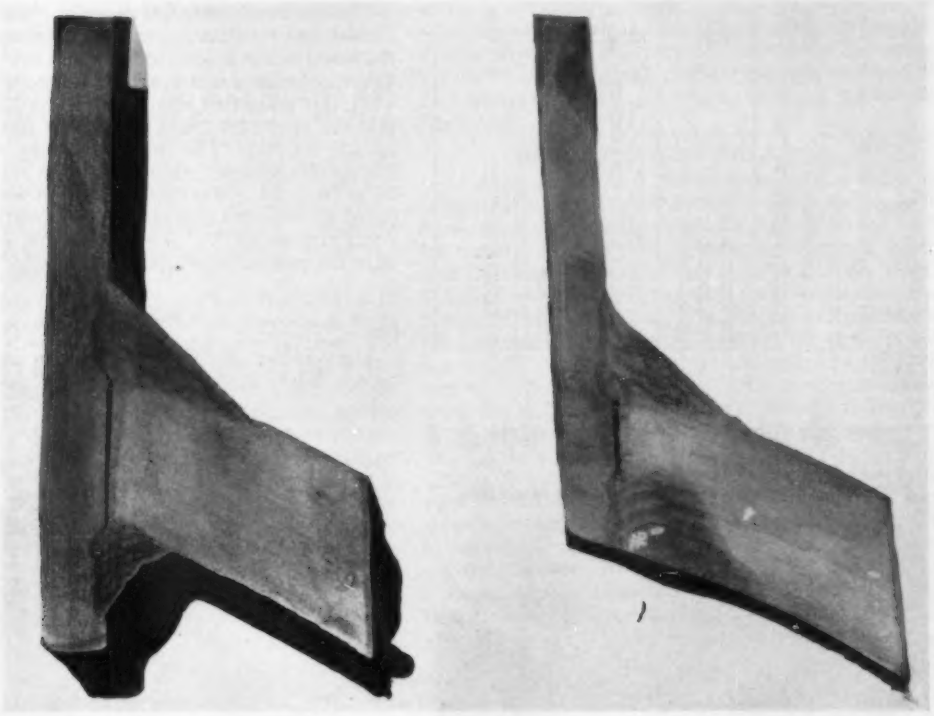
The specimens were subjected to pulsating internal pressure, using the special test plant which has been described before.[4] The limits for all the tests were: upper, 2000 lb/in²; and lower, 100 lb/in². Taking the average dimensions of the shells as measured, the upper pressure would produce a mean hoop stress of 9·1 tons/in².

The shape of the load cycle is generally saw-toothed, the loading portion occupying about nine-tenths of the time required for one complete cycle. The maximum pressure limit is controlled to ±50 lb/in², which represents a variation in mean hoop stress of ±0·23 tons/in².

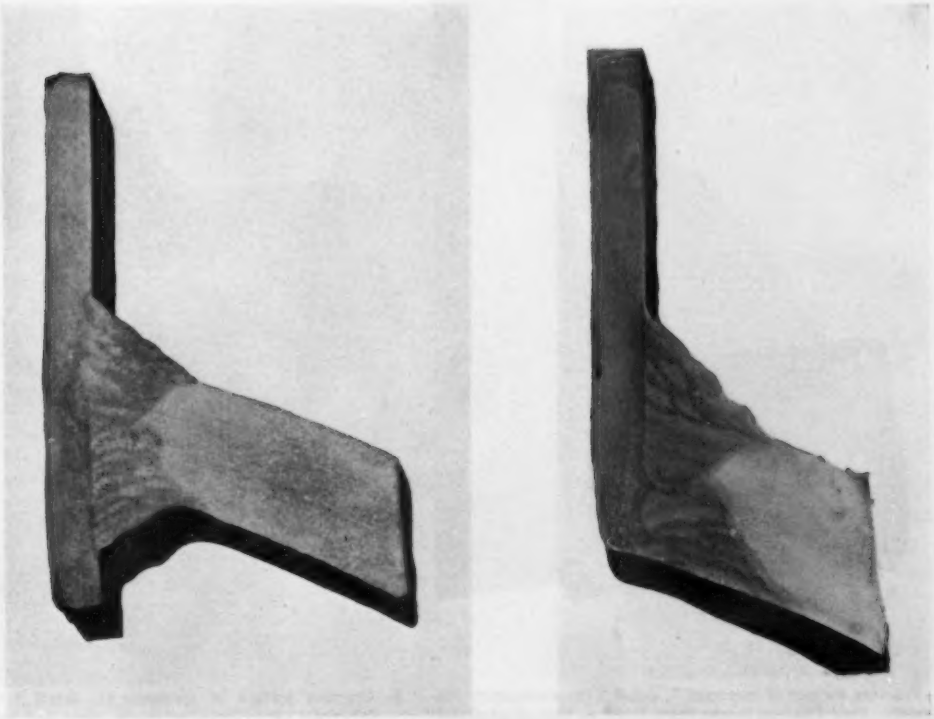


1—Weld details

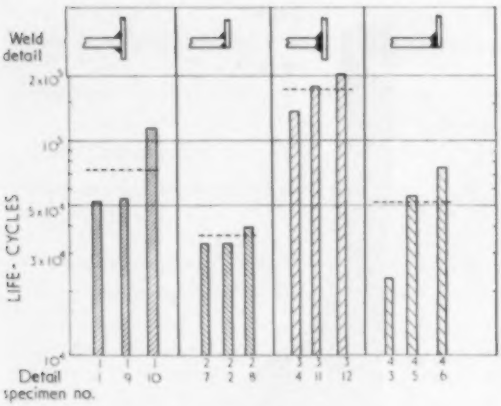
(*a*)
Details 1 and 2



(*b*)
Details 3 and 4



2—Photomacrographs of welds (approximately full-size)



Maximum pressure for all specimens such as to give a mean shell hoop stress of 9·1 tons/in² (P = 2000 lb/in²). Dotted lines are averages of three specimens.

3—Pulsating pressure tests on shell to nozzle connections

The specimens were considered to have failed when a crack had penetrated completely through the wall of the vessel or the branch so that fluid could escape. No automatic means was available for stopping the plant when this point had been reached, so it was arranged that the attendant could inspect the specimen at ten-minute intervals. The speed of testing was approximately 60 cycles per minute, and thus any result could be in error by +600 cycles, which is negligible compared with the test results. The pressure fluid used was water containing 3% of soluble oil in order to minimize the possibility of corrosion effects.

RESULTS

Life

The number of cycles sustained by each specimen before failure is shown in Table II. These figures are

4—Fracture surface of specimen 7, detail 2 (approximately full-size). *Note* fracture origin from inner surface of shellplate (arrowed)

5—Fracture surface of specimen 11, detail 3 (approximately full-size). *Note* fracture origin from the inner fillet weld (arrowed).

represented graphically in Fig. 3, where a logarithmic scale of life has been used.

Mode of failure

All specimens failed by a crack in the shell radial to the branch. This crack extended to a greater or lesser degree up the branch itself. With one exception, all the failures were within 10° of the longitudinal section plane of the vessel; this is the plane on which the maximum stresses were found in the experimental stress analysis work. Specimen 9 failed by a fracture radial to the branch approximately 45° from the longitudinal section plane of the shell.

An inspection of the fracture surfaces showed that in all cases, except one, the fatigue failure commenced from the inside of the vessel. In the majority of cases, the cracks originated at the inner surface of the wall of the vessel. In some cases, the fracture started from the toe of the inner fillet weld where this joined the shell, and in three cases the origin appeared to be spread over the whole surface of the inner fillet weld. The only case where the fatigue failure started from the root of a weld is in specimen 10. This specimen also shows an extensive crack circumferential to the branch in the heat-affected zone of the inner fillet weld, where this oins the shell.

Specimens 5, 6, 7, 8, and 11 each had two fractures 180° apart. Figures 4 and 5 show typical fracture surfaces for designs 2 and 3, and Fig. 6 shows the fracture surface in specimen 10, the only instance of failure originating from the root of one of the welds. Figure 7 is a general view of the fracture in specimen 9. This shows that the branch material was considerably laminated.

DISCUSSION AND CONCLUSIONS

As is shown in Fig. 3, the average number of cycles sustained by the four different details varied from approximately $3{\cdot}6\times10^4$ cycles for detail 2 to $1{\cdot}7\times10^5$ for detail 3. It is difficult to know whether this difference is in fact significant. The consistency of the results obtained with detail 3 suggests that, under the conditions of the tests, its fatigue life is greater than that of the other details examined. However, the corresponding detail 1, where the branch is attached to the shell merely with two fillet welds each having a throat thickness equal to the wall thickness of the branch, shows results little lower than those obtained from detail 3. In considering the figures for various details, it must be borne in mind that the normal scatter to be expected from fatigue results is considerable and, since only three specimens of each type were tested, it is concluded that there is little evidence for differentiating between the four details.

Experimental stress analysis work has shown that the stress concentration close to a branch which is

6—General view of fracture of specimen 10, detail 1 (approximately full-size). Fracture commences at root of inner fillet weld (arrowed). *Note* **crack around toe of fillet weld on shell plate.**

allowed to protrude on the inside of a shell is only little more than half that around a branch which is flush on the inner surface. This difference between the two types of design is not as marked in the results of the pulsating pressure tests as might have been expected. The probable explanation for this is that, with the protruding branch, the free surface at the point of maximum stress concentration is the surface of the inner fillet weld. This was left in the as-welded condition, and the normal welding ripples would therefore provide an additional local stress concentration. With the branches which were flush on the inside surface, the inner weld was carefully dressed off flush with the shell, and it would be expected, therefore, that the only source of stress concentration would be that due to the branch opening. In this way, the difference in stress concentration between the two types of design is slightly reduced.

7—General view of fracture of specimen 9, detail 1 (approximately full-size). *Note* laminated structure of branch pipe

The important feature of the fractures is that in only one of the twelve specimens did the fatigue crack start from the root of the weld. In the remainder of the specimens the location of the crack did not depend upon the weld detail, indicating that the differences between these are less important than the conditions at the internal surface of the vessel. The only specimen in which the fracture was located away from the longitudinal section plane of the shell exhibited considerable lamination of the branch pipe, as shown in Fig. 7, and this is probably the explanation for the location of the failure.

Some results for pulsating-tension fatigue tests on $1\frac{1}{4}$ in. thick mild-steel plate, which had been stress-relieved and tested with the mill-scale remaining, have been compared with the results of the tests reported herein. It has been shown previously that the elastic stress-concentration factor close to a branch which protrudes into the vessel is approximately 2·2; if the mean hoop stress in the shell at the maximum pressure (9·1 tons/in^2) is multiplied by this stress-concentration factor, the resulting theoretical elastic stress is 20 tons/in^2. For a life of 2×10^5 cycles the stress limits for the flat plates were 0–$19\frac{1}{2}$ tons/in^2. If the fatigue life of the composite specimen is dependent upon the maximum elastic stress, it would be expected, therefore, that the life would be slightly less than 2×10^5 cycles. In fact, the average life of specimens to design 3 (which had a protruding branch with a full-penetration weld) was $1{\cdot}7\times10^5$ cycles.

ACKNOWLEDGMENTS

The work described in this report was carried out as part of a comprehensive investigation of branch connections in pressure vessels, being supervised by the British Welding Research Association's FE.12 Committee on Stresses in Welded Pressure Vessels. The author wishes to express his thanks to the Chairman, Mr. J. H. N. Thompson, and members of the Committee, for their helpful advice. The author's thanks are also due to his colleagues, Mr. E. O. Lawrance, Mr. H. R. Bowen, and Mr. J. Turner for their work in the preparation and testing of the specimens.

This report is published by permission of the Council of the British Welding Research Association. Any opinions expressed are, however, those of the author alone.

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NEWS
and Announcements

News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE OF WELDING—Spring Meeting 1958

The Annual Spring Meeting was held at Harrogate on 7th–10th May, with the co-operation of the Leeds and District Branch. In spite of inclement weather, which disappointed those who had hoped to play in a Golf Tournament on the Wednesday before the opening of the meeting, the technical sessions and works visits were well attended.

The meeting commenced with visits on the Thursday to works in Wakefield, Leeds, and Bradford. Further visits were made on the Friday afternoon to works in Leeds, Shipley, and York.

Two technical sessions for the discussion of papers were held, one dealing with welded steel railway coaches and diesel engine frames, and the other with the welding of aluminium bronze and the fabrication of plant for chemical and general industrial use.

A well-attended dinner was held at the Majestic Hotel on Friday evening, the principal guest being the Mayor of Harrogate, Councillor Miss A. V. Wardle, J.P. The Mayor responded to the toast of the Guests, proposed by Mr. A. Robert Jenkins, J.P. (Past-President). The toast of the Institute and of the Leeds Branch was proposed by Mr. C. W. Mustill, M.B.E., Chairman of the Leeds Productivity Association, and the response was made by Mr. Rowland Gardner, Chairman of the Leeds Branch of the Institute.

Works Visits

Richard Sutcliffe Ltd., Horbury, Wakefield. The Company, an old family concern, specializes in the fabrication and installation of conveyor equipment for mining and surface movement of materials. The party first saw three films, showing the use of equipment for the winning of iron ore, filling of cement bags, and removal of soil at a refinery site. These gave an important overall view of the equipment made by the Company in a way that would have been impossible from inspection of the components being fabricated in the works.

These are specialized items, and welding is used solely as a method of construction for the supporting frameworks of the conveyor systems. The material is generally mild steel and no special welding problems arise.

The visitors were struck by the happy atmosphere in the works and the humble approach of the management to the problems that arise.

English Electric Company Ltd., Bradford. This branch of the Company is devoted almost entirely to the production of electric motors. The guides to each of the small parties of visitors made the tour of the various departments as interesting as possible, with ready explanations in lay language. They showed the machining of the components, the winding of rotors and stators, and the final assembly and testing.

One large Test House received particular attention; it housed 'high-altitude' chambers for the testing of motors and electrical equipment under simulated conditions of temperature and pressure experienced by aircraft from ground level to 100,000 ft.

J. & H. McClaren Ltd., Leeds. This firm fabricates diesel engine components and bedplates, marine gearboxes, pressure vessels, and the like. During the tour of the works the visitors saw plate preparation, and various stages in the manufacture of machinery parts. Stress-relieving furnaces and the inspection of finished welded parts were also seen.

An interesting part of the tour was an inspection of the diesel engine assembly and testing bays.

Clayton, Son & Co. Ltd., Leeds. The products of this company are mostly tubes and pressure vessels for high-duty operation. At the Moor End Works the visitors were shown the concrete lining of 60 in. dia. tubes, and the submerged-arc welding of tubes and flat plates. Particular interest was paid to the water-gas welding of tubes for the oil drilling industry, a process adopted and used by the Company for the past fifty years.

The party also witnessed the pickling and painting of plates and the metal spraying of tubes. The X-ray plant was also visited.

W. P. Butterfield Ltd., Shipley. Manufacturers of road tanks, storage tanks, stainless steel equipment for the chemical, food, and allied industries, this Company has existed for more than seventy years. A large party of visitors was shown over the extensive No. 1 Works, where mild steel and stainless vessels of all forms were seen in various stages of manufacture. Particular interest was shown in the wide range of manipulative equipment used and in the methods developed for cutting and forming intricate shapes for the ends of vessels. Great interest was also shown in the presses, themselves welded fabrications, used for dishing the hot plates from the adjacent furnaces.

The recently built research and development laboratories were also inspected; they are to be equipped with a wide range of testing, inspection, and analytical apparatus.

A fascinating tour ended with a view of the galvanizing shop and a general aspect of completed tankers and stainless vessels.

British Railways Carriage and Wagon Works, York. All-welded underframes for railway coaches represented the heavy side of the fabrication work seen by the visitors, and considerable interest was shown in the methods adopted to prevent distortion and contraction. The extensive use of elaborate jigs wherever possible was a notable feature.

The welding of light-gauge steel to form the skin of the coaches prompted many questions that were ably answered by the guides.

Kirkstall Forge Engineering Ltd., Leeds. This firm was established in the 17th century on a site where the monks of Kirkstall Abbey had been associated with the forging of metals since the 11th century.

Visitors were first shown round the forging shops where they saw a large variety of steel forgings in process of manufacture. In the machine shops, where the forgings are subsequently finished, the party was

considerably impressed by the wide range of machine tools and special equipment used and by the high class quality finish they gave to completed units.

Another item of great interest was the drawing of steel wire and rod from billets.

Yorkshire Imperial Metals Ltd., Leeds. This relatively new company manufactures non-ferrous tubes and fittings. The party of visitors was first entertained by a film, which gave an excellent illustration and description of the processes carried out in the works. As well as the interest provided the film was of great assistance in following the processes during the subsequent tour of the extensive works. The party was able to see the various methods used to make non-ferrous tubes, from the melting furnaces, casting of ingots, piercing, rolling, and drawing in various types of machine, to the finished product.

In all the works visited the management provided a ready welcome and generous hospitality. The guides, who probably had to suffer later from a day's lost work, led the parties with admirable patience through a complexity of operations, and were ready to answer the most awkward and searching questions. To managements and staff alike the Institute gives its warmest thanks. A large part of the success of the Institute's annual meetings is due to the interest shown in visits such as these, and most of the credit must go to the companies which provide the facilities for members to see at least part of what 'the other half of the world' is doing.

Sir William J. Larke Medal

As announced in the January issue of the *Journal* the 1957 award of this medal, the highest award that can be bestowed by the Council, has been made to Mr. M. Noone and Mr. W. C. Holliday for their paper "Welding of Spheres and Bullets *in situ*".

The actual presentation was made during the first technical session of the Spring Meeting at Harrogate on 9th May.

Symposium on Aluminium Pressure Vessels

In collaboration with the Institute of Welding and the Aluminium Development Association, the Institution of Mechanical Engineers is arranging a Symposium to be held on Tuesday, 28th October, 1958. Registration forms can be obtained from the Institution at 1 Birdcage Walk, Westminster, London, S.W.1.

Further details will be announced in the *Journal*.

NEWS OF MEMBERS

The Council regret to announce the deaths of the following members:

T. Fairhurst, Associate, of Manchester; **J. P. K. Hamilton**, Associate-Member, of North London; **A. A. Marks**, Associate-Member, of West Scotland; **Shri B. N. Mohindra**, Vice-Chairman of the Indian Branch; and **G. V. Slottman**, Member, of New York.

J. S. Terrington, Head of the Civil Engineering Section of BISRA's Plant Engineering Division, has been awarded a Ph.D. degree of London University in the Faculty of Engineering.

D. J. W. Boag, Managing Director of Rockweld Ltd., is now on an extensive tour of Canada and the U.S.A. He will be visiting the Company's subsidiary, Canadian Rockweld Ltd., of which he is President.

D. F. T. Roberts has left Murex Welding Processes Ltd. to join the G.E.C.-Simon Carves Atomic Energy Group, Erith, Kent, as a Welding Engineer.

CONTRIBUTORS TO THE JOURNAL

Sir **Alfred Pugsley**, O.B.E., D.Sc.(Eng.), F.R.S., has been Professor of Civil Engineering in the University of Bristol since 1945. He took part in the planning of the new University Engineering Laboratories, and was Dean of the Faculty of Engineering from 1951 to 1954.

He was educated at Rutlish School, Merton, Surrey, and at London University from which he graduated B.Sc.(Eng.) with First Class Honours in 1923. He then trained as a Civil Engineering Student Apprentice at the Royal Arsenal, Woolwich. In 1926 he joined the design and research staff at the Royal Airship Works at Cardington. In 1931 he was appointed to the scientific and technical staff at the Royal Aircraft Establishment at Farnborough, and from 1941 to 1945 he was Head of the Structural and Mechanical Engineering Department.

For his thesis on the lateral stability of beams Sir Alfred was awarded the M.Sc. (Eng.) degree of London University in 1930; this was followed by a D.Sc. degree eight years later. He was awarded an O.B.E. in 1944. Professor Pugsley was elected President of the Institution of Structural Engineers for the session 1957–58, having served as a Vice-President since 1952. He has been actively engaged in the affairs of the Western Counties Branch of that Institution. In 1952 he was elected a Fellow of the Royal Society, and in 1956 he received the honour of a knighthood.

Sir Alfred Pugsley

F. Fidgeon, B.Sc., is Lecturer in Metallurgy at the Luton and South Bedfordshire College of Further Education. He received his early education at the West Hartlepool Grammar School, and later graduated with B.Sc.(Honours) in Metallurgy from King's College, University of Durham.

Before taking up his present position he worked as an investigator at the British Welding Research Association and at the British Non-Ferrous Metals Research Association.

B.W.R.A.

Annual Luncheon 1958

There was a very large attendance at the Annual Luncheon of the Association on Wednesday, 11th June. The President of the Association, Sir Charles Lillicrap, K.C.B., M.B.E., D.Sc., presided, and the Principal Guest was Sir Claude Gibb, K.B.E., D.Sc., F.R.S. For the first time since the Association was formed, Sir William Larke was unfortunately not able to attend. A message of goodwill was sent to him.

In proposing the toast of the Association, Sir Claude spoke of the proposed further extensions at Abington to provide office accommodation and a welding shop. As one of the founders of B.W.R.A. he was able to look back over the past 12 years and to praise the Association for its achievements during that time. This demonstrated that the vitality of the staff and its leaders was more important than the splendour of its buildings. After recalling how welding had received a great impetus from weapon production during the last war, Sir Claude said that the Association's work on the welding of thick plate was a major factor in the development of the peaceful use of atomic energy, itself resulting from another more terrible weapon.

The reply to the toast was made by Mr. A. Robert Jenkins, J.P., Chairman of Council, who referred again to the proposed buildings and said that except for the retention of a small staff and the holding of meetings in London the activities of the Association would be centred at Abington. Referring to the signs of more difficult times ahead, Mr. Jenkins expressed the hope that industry would consider it to be perilous to economise in its support of the Association's researches.

The usual Exhibition of Work in Progress was held in conjunction with the Luncheon. Some of the features shown will be described in a later issue of the *Journal*.

NEWS FROM INDUSTRY

Exhibition of Resistance Welding Equipment

Multiple spot welders, both standard types and special purpose machines, are to be exhibited and demonstrated at the works of Bates & Bates Ltd., Blackburn Street, Garston, Liverpool. The display is being held from 8th to 11th July, and admission is by invitation.

Many of the machines will be fitted with hydraulic and pneumatic controls to give a high degree of automation.

Anniversary

In May, Welding Supplies Ltd., of Gillingham, passed the 25th anniversary of their formation. In the past quarter century, which has seen so much progress in welded fabrication, the Company has established a sound reputation in the industry. Among notable achievements are the introduction of the O.K. range of electrodes and more recently of the K.B.375 welding generators,

of which nearly 100 are being used in the construction of plant for the Berkeley nuclear power station.

New Vacu-Blast Premises

Increased demand for the Vacu-Blast closed-circuit system of shot blasting equipment has led the company to seek new buildings to facilitate greater production.

The Company's factory and offices are now at Bath Road, Slough, Bucks., with telephone Slough 24507.

The extra accommodation provided and additional manufacturing facilities will allow continued development of the system to cover a wider range of industries.

Industrial Gas Production in Scotland

British Oxygen Gases Ltd. announce that they have started the building of a new factory for the production of industrial gases at a site close to the existing factory at Polmadie near Glasgow. The project is being designed by British Oxygen Engineering Ltd., and the building contractors are John Laing & Sons.

Nuclear Power Group

A new company, the English Electric Babcock & Wilcox and Taylor Woodrow Atomic Power Construction Company Ltd. has been formed to administer the contract for the nuclear power station at Hinckley Point, Somerset. The construction of the plant, which commenced last autumn, will be carried out by the three companies comprising the group under subcontracts with the new company.

Wilmot Breeden Fellowships

The Wilmot Breeden Group of Companies, whose manufacturing interests include motor vehicle and gas turbine components, hydraulics and electronics, are sponsoring two Fellowships, each worth £1,000 per annum, one at the University of Birmingham and the other at the College of Technology. An unusual feature of these Fellowships is that the successful candidates will divide their time between the University or College and the Company.

Each Fellowship will normally be held for a period of two years. A candidate for a Fellowship should normally have had two or three years research or industrial experience. He must be acceptable to the academic authority and would be expected to have an honours degree in a University in the British Commonwealth, a Diploma in Technology, or an equivalent qualification. An application for a Fellowship should outline a two-year investigation or project on which the candidate seeks to work.

Enterprises on which candidates are expected to work include mechanism, electrochemistry, metal finishing, metallurgy, metal formation, hydraulics, electronics.

Summer School on the Principles and Practice of Non-Destructive Testing

A Summer School on the Principles and Practice of Non-Destructive Testing, intended to benefit senior and chief inspectors from industry, is to be held at the Manchester College of Science and Technology on 8th–12th September, 1958. This Summer School has been sponsored by the British National Committee for Non-Destructive Testing, of which the Institute is a member, and is being organized by the Manchester College of Science and Technology, the Manchester Association of Engineers, and the Institution of Engineering Inspection.

Those attending the course are expected to have some basic knowledge of non-destructive testing techniques. The physical background of the subject and the interpretation of test results will be the dominant themes of the course.

The total cost of the course is expected to be approximately £18. Accommodation for those attending will be provided in the residential quarters of Hulme Hall. For further details, please apply to the Organizing Lecturer, Dr. J. H. Lamble, Ph.D., D.Sc., M.Eng., M.I.Mech.E., Manchester College of Science and Technology, Manchester, 1.

Welding Training at Darlington Technical College

A new College of Further Education, which has been recently opened at Darlington at a cost of about £180,000 includes a welding school which can accommodate about 40 students. Courses are given in both oxy-acetylene welding and in arc welding.

The Volta Bridge

At a meeting of the Institution of Civil Engineers, held on 13th May, a paper on the design and construction of the Volta Bridge in Ghana was presented by P. A. Scott and Gilbert Roberts.

The bridge is a steel arch structure with a clear span of 805 ft., and is the largest to be built in welded high-tensile steel to BS.968. The main compression members are box sections made up from four welded plates with internal diaphragms. The longitudinal welds were made by the submerged-arc process, using two machines in tandem.

The diagonal members are all of double channel section with welded batten plates. The lateral arch bracing members are made up of double channels connected by light channel section lacing members.

The cross girders and stringers for the deck are also of high-tensile steel welded construction.

Very careful attention was paid to the sizes of welds to avoid any chance of cracking, and the results of previous work by the British Welding Research Association were used to prepared graphs from which the minimum sizes could easily be determined. No preheating was founded to be needed. Mild steel electrodes with rutile coatings were specified for manual welding and mild steel wire for the automatic submerged-arc process.

One surprising feature of the detail design is the use of small edge covers on the flange splices of the cross girders where these are in tension. The authors state that these covers mitigate the notch effect that might be introduced from rough removal of the continuation plates used to make the butt welds. Yet one would expect the covers to provide a more severe notch than that presented by a flame cut and ground edge to the weld.

The steelwork was fabricated by the Cleveland Bridge & Engineering Company to the designs of the Consulting Engineers, Sir William Halcrow & Partners and Messrs. Freeman Fox & Partners. The main contractors were Dorman Long (Bridge & Engineering) Ltd. All those concerned are to be congratulated on their courage in undertaking a pioneering venture of this magnitude.

Suspension Footbridges

Footbridges of novel design have been used by the Forestry Commission for crossing streams and rivers. They are made up of floors and sides of Weldmesh fabric (made by the B.R.C. Engineering Co. Ltd.) suspended on steel cables. This method provides adequate strength with the advantages of low cost and simplicity of erection.

One recent bridge, crossing the River Wye in the Forest of Dean, spans 200 ft and can carry a gang of 40 men. It was designed by the Directorate Engineer, Col. R. H. Packwood, and was erected by local forest labour.

Welding of 'Sno-cat' Tracks

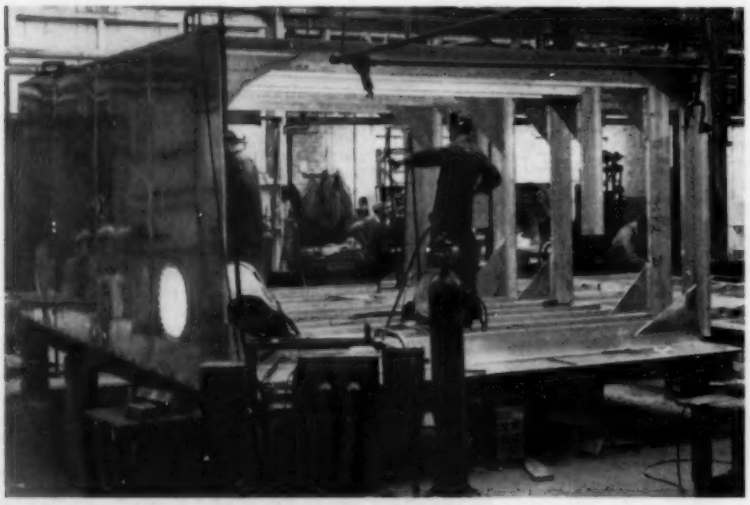
Some of the most arduous conditions possible were experienced by the Sno-cat tractors used on the recent Trans-Antarctic Expedition. As a result of controlled metallurgical tests the welds in the flexible tracks of the vehicles sustained no damage and there were no failures during the whole journey across Antarctica. The weight of the Sno-cat is carried on four pontoons and traction is provided by a flexible track around each pontoon. The units of the track consist of two alloy steel castings, attached

Weldmesh bridge over River Wye

to the ends of a 2 ft. length of medium carbon steel tube by welding. During proving and training runs of the vehicles in Norway, some of the welds in the track units cracked, causing failure of the tracks. When the vehicles returned to England, specimens of the failed units were submitted to the British Welding Research Association laboratories at Abington, Cambridge. Examination of the welds between the carbon steel tube and the alloy steel casting showed that the welds had not been made under satisfactory metallurgical control.

On the recommendations of the Association, it was decided to machine out all the original welds and to re-weld the units under careful metallurgical control. Several tests were carried out to decide on a suitable heat-treatment cycle which would avoid excessive hardening in the zone adjacent to the weld and prevent cracking of the welds. The procedure finally recommended involved pre-heating the castings in a furnace before welding and returning them to the furnace immediately welding was completed so that the rate of cooling could be controlled.

All the track units from the three vehicles shipped from this country in November 1956, together with seventy spare units, were re-welded in this way by the staff of the British Welding Research Association.



Inert-gas welded light alloy tanks

Light Alloy Water Tanks

Two welded light alloy tanks, the largest of which measures about 30 ft. × 12 ft. × 5 ft. and weighs over 4 tons, were recently completed by Windshields of Worcester Ltd. They have been fabricated by the inert-gas metal-arc process from ¼ in. thick MG5 plate stiffened with extrusions of the same material, supplied by James Booth & Co. Ltd.

The tanks, which are believed to be the largest prefabricated for marine use, are to hold 11,000 gallons of fresh drinking water on two Caltex oil tankers being built in Belgium.

'Speedforge' Projection Welders

A new, fully automatic, general purpose projection welder has been designed by Sciaky Electric Welding Machines Ltd., Slough, for operation by unskilled labour.

Its most important feature is a one-piece frame made from solid welded steel billets. This avoids many of the disadvantages of earlier types, and provides rigid parallelism of the platens as well as a direct current connection to the lower arm, so that arcing of contacts is avoided.

The control buttons have been placed on the lower arm so that they are within easy reach of the operator.

The frame houses the welding transformer and its tapping switch, and also, in the smaller size machines, the primary current contactor. Hinged wing panels, which protect this equipment, can be opened to give complete all round accessibility. Where the primary contactor is integral with the frame, the electronic timing control gear is incorporated in a separate cabinet and mounted on top of the machine, where the dials can be seen and adjusted from the work station. This feature also applies to the air controls. The larger machines in the range have a separate pedestal mounted cubical which contains the timing controls, the primary ignitron contactor, and a phase shift heat control unit.

The fully interlocked control circuit is operated by a Sciaky three-channel electronic unit which provides variable timing for the 'squeeze' period prior to the weld—the actual weld time and 'hold' period when the electrodes remain closed to give extra forging action. This programme control has the following ranges: squeeze and hold 2 to 75 cycles; weld period 2 to 150 cycles. Indicator lights show when the panel is switched on and when the valves are ready for operation. Additions or variations to the programme, such as two and three air pressure cycle, pre-weld heat and post-weld annealing currents, can readily be provided.

A double-acting pneumatic cylinder, fed by an electrically operated air valve, applies electrode force set to the required value by a reducing valve and pressure gauge. Composition piston seals are employed and a vernier throttle cushions the downstroke to reduce the hammering effect on the work pieces.

Power Unit for Argon-Arc Welding

Surge injection, a method of 'self-starting' the arc, is incorporated in a new composite power unit CPU 350 which is now being marketed by the Industrial Division of British Oxygen Gases Ltd. It can be used for the argon-arc welding of aluminium and its alloys up to ⅜ in. thick and stainless steel up to ⅛ in. thick.

A remote control foot switch, coupled with automatic arc starting and control of both argon and water enables welding speed to be increased. After the Unit has been switched off, the electrode cools in the protecting argon envelope, the gas continuing to flow automatically for a predetermined period. This results in economy of gas and ensures that the cleanliness of the electrode is maintained.

The unit is suitable for 360–500 V, 50 cycle, single-phase operation, with a striking voltage of 50 V. Rating is 10·75 kVA continuous or 17·5 kVA at 50% duty cycle. Welding current is 25 to 350 A, and 215 A continuous.

High-pressure Welding and Cutting

A comprehensive set of welding and cutting equipment for use with dissolved acetylene or the gas from high-pressure generators is now available from D. S. Baddeley Engineering Co. Ltd. The "Clyde" equipment is capable of welding material from $\frac{1}{32}$ to ⅜ in. thickness and of cutting sheet steel or mild steel up to 4 in. thick. Special attention has been paid in the design of the blow-pipe to the comfort and safety of the operator.

Deep-penetration Welding

For deep-penetration welding of mild steel Rockweld Ltd. have introduced a new electrode 'Penetrac'. For making butt joints in plate up to about ½ in. thickness deep penetration electrodes avoid the need for edge preparation and reduce the amount of weld metal needed for complete fusion. A special application intended for this electrode is in the fabrication of castellated beams.

High-speed Metal Spraying

A high-speed semi-automatic metal spraying unit—the Metco Type *K* metallizing machine—has been produced by Metallizing Equipment Co., Ltd., of Chobham, Woking. Intended for use either as an individual unit or as a part of a larger production set-up, the equipment can deposit suitable wire facing metal to thicknesses from 0·001 to ½ in. or more. The operation is based on the same principles as existing Metco equipment.

The Company has also recently developed a completely portable truck to accommodate all the necessary equipment for normal metallizing operations.

B.K.B. Welding Generator

A versatile d.c. welding generator that can be direct or belt driven from engine, electric motor, or line shaft has been produced by B.K.B. Electric Motors Ltd. It has a drooping characteristic and provides

300 A at continuous rating or 400 A intermittently. An open-circuit voltage of 45–78 V provides adequate striking voltage. A separate variable rheostat control enables any particular current and arc voltage to be established with ease.

Furnace Heating Elements

To demonstrate the advantages of silicon-carbide heating elements, a small Crusilite Slot-Type forge furnace has been installed at the Midland Electricity Industrial Development Centre, Dudley, Worcs. It has been designed to heat billets to 1250°C. at the rate of 130 lb/hr.

Crusilite is manufactured by the Morgan Crucible Co., Ltd., in a wide range of sizes and electrical resistance values, and can be used in 11 temperature ranges up to 1500°C.

Heavy-duty Helmets

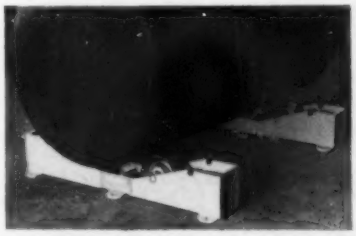
Made under Licence 2820 to the British Standard 2826:1957, the "Lifeguard" industrial safety helmet has recently been produced by Panorama Equipment Ltd. Of aluminium alloy construction, the helmet is claimed to exceed the stringent requirements of the specification and also the U.S. standards. It weighs 13 oz. complete and is adjustable to all sizes.

Plastic Welding Goggle

A lightweight plastic goggle suitable for welding operations has been produced by Safety Products Ltd. It has replaceable lenses of non-flam green acetate and baffled ventilators fitted with wire gauze inserts.

Idler Rotators

Most fabricating shops needing rotators for manipulating cylindrical equipment for manual welding make up their own devices from scrap material. These are not always as accurate and efficient as they should be,



and it is interesting to learn that Courtburn Positioners Ltd. have produced a range of low-cost rotators built to the same degree of accuracy and robustness as their larger models. The equipment is available in four sizes to accommodate vessels from 1 ft. to 13 ft. 6 in. dia.

Technical Papers

Copies of technical papers that have been recently presented by the staff of Quasi-Arc Ltd. to Branches of the Institute, and to other metallurgical and engineering societies, are available from the Company's offices at Bilston, Staffs.

Openings in the Steel Industry

A series of three small booklets—"Careers for Graduates", "Careers in Research and Development", "Training for Student Apprentices"—has been issued by The United Steel Companies Ltd. Each describes briefly the Companies' activities, the opportunities open to scientists and engineers in the many branches of the Group, and the methods of recruitment and training.

Industrial Safety Helmets

A new British Standard B.S.2095:1958 covers the materials, construction, and testing of light-duty protective helmets for use in mining, quarrying, and similar occupations.

Precision Tubes

Those working on the fabrication of components for nuclear energy plant will be interested in a new brochure produced by Accles and Pollock Ltd., Oldbury. Entitled 'Precision Tube Developments' it describes concisely the ranges of special tubes that have been developed by this Company, most of which have some application as fuel elements or as heat exchanger components.

Other items described include helically convoluted flexible tubing, gilled tubing in mild steel and in other metals, thin walled and capillary tubing, multibore tubes and Bourdon and high-pressure tubing.

Welding Titanium Alloys

Brief but adequate general information on the welding techniques to be employed in the welding of titanium alloys is contained in the latest issue of the William Jessop Information Sheets (No. M783). Details include the argon arc welding of sheet and bar, the spot and seam welding of sheet, and flash welding—all in the company's range of Hylite alloys.

Thermal Properties of Metals

The results of an experimental determination, by the Battelle Memorial Institute, of the main thermal properties of thirteen metals have now been published. Special Technical Publication No. 227 (price $1.25) of the American Society for Testing Materials contains extensive information for two grades of aluminium, chromium, copper, two grades of Inconel, magnesium, molybdenum, Monel K, and four grades of steel.

Safety in Welding and Cutting

The American Welding Society's Standard Z49, published in 1944, has been completely revised and brought up to date. In particular the precautions needed when dealing with the newer welding processes are covered in detail. Copies of the new Standard (Z49.1) are available from the Society at $2.0 a copy.

STUB ENDS

▶ The ASME Special Technical Publication No. 216 deals with the results obtained from large scale fatigue tests.

▶ Quasi-Arc Ltd. have appointed Mr. N. H. Townend as Publicity Manager at Bilston.

▶ The British Oxygen Company have appointed Mr. R. C. Hesketh-Jones Chief Executive (Overseas) at Head Office. His position as Sales Director (Industrial Division) is being taken by Mr. R. J. Foster.

▶ John Scott has been appointed by the British Welding Research Association as Press Liaison Officer.

▶ The Head of the Physics Department at BISRA's Battersea laboratories is now Mr. S. S. Carlisle, who was formerly Head of the South Wales laboratories at Sketty. Mr. W. N. Jenkins of the Electrical Engineering Section of the Plant Engineering Division is to take over the duties of Head of the South Wales laboratories.

▶ Swan, Hunter and Wigham Richardson, of Wallsend, is to collaborate with the Nuclear Power Plant Company in the building of nuclear-powered merchant ships.

CLASSIFIED ADVERTISEMENTS

Situations Vacant

Engineers in the Trafford Park area require a **Welding Engineer** who must have practical experience in Gas and Electrical welding up to Grade *A* standard and must be also familiar with argon and submerged-arc processes. Some metallurgical knowledge is desirable but not essential. This is a superannuable staff position with excellent prospects. Applicants must give full particulars and mark applications "For the attention of the Personnel Manager", Box No. 219.

Metallurgist required to fill a research post in South London related to welding. Applicants should have an Honours degree or equivalent qualification, some experience of fabrication or of smelting. Commencing salary £950. Box No. 221.

Welding Engineer required for the promotion of new and interesting arc welding processes. Successful applicant must be free for extensive travel because work will entail lecturing, demonstrating, and selling in a wide area of the British Isles, working in co-operation with existing sales force.

First-class welding skill and wide knowledge of welding applications essential; experience with inert-gas arc processes desirable. Applicants should be young and energetic with enthusiasm for sales work and academic qualifications in metallurgy and/or engineering will be an advantage.

Please reply in confidence giving full particulars to Box No. 222.

MSL have been retained to advise on the appointment of a

WELDING ENGINEER

for a company of 2,000 employees engaged in boilermaking, heavy engineering and shipbuilding in the West of Scotland.

The Welding Engineer will be responsible for advising on welding problems arising at any stage from initial design to final erection at site. He will be expected to improve and codify the company's welding practice, advise on the purchase of welding equipment and supplies and ensure that the company's welders maintain a high level of competence.

Candidates should have a thorough knowledge of welding codes and modern welding processes for pressure vessels, boiler drums, heavy fabrications and pipework in mild and alloy steels and of all forms of non-destructive testing. A knowledge of metallurgy would be an advantage. Membership of the Institute of Welding would be an additional recommendation. Preferred age at least 35.

Starting salary not less than £1,750; considerably more could be offered to a candidate with particularly relevant experience. Removal expenses will be paid.

No information will be disclosed to our clients until candidates know their identity and have given permission after personal discussion. Please send brief details in confidence, quoting reference HW.945, to T. E. Watson.

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Current
WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

THIS SECTION is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the *Bibliographical Bulletin of Welding and Allied Processes*, published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.

Welding Journals

Canadian Welder, 1958, vol. 49, February

Welding developments in the fabrication of pressure vessels (12–14)

The effect of explosion tests on arc-welded tubes, E. Folkhard (condensed by H. J. Nichols) (16–18)

New German automatic welding process (20)

Canadian Welder, 1958, vol. 49, March

Hardfacing techniques (14–16)

Canadian company develops all-welded cable reels, G. F. Liddell (18–19)

In Northern Ontario Trans-Canada Pipelines encounters world's toughest pipeline, W. G. McFarlane (22–24)

Industry and Welding (U.S.A.), 1958, vol. 31, April

Semi automatic welding, Herb Hinkel (47)

These are processes that use flux shielding (48–49, 108)

. . . And here are the processes that use gas shielding (50–51, 108–109)

This automatic brazing cycle boosts output 160% (52–53, 80)

Three ways to weld aluminium without porosity (56–57, 80)

90 welding arcs from a single power source (58–59, 116–117)

3 places where spot welding saves time (60–61)

Arc welder maintenance, Stanley Krapp (72, 75)

Flame camber your own beams, Hank Ciesicki and S. Butler (76, 78–79)

Journal of the Japan Welding Society, 1958, vol. 27, February

Review of welding in European shipbuilding, T. Yoshida (2–4)

Propagation and arrest of brittle fracture in wide steel plate (5–10)

The influences of oxygen upon the consumption-rates of iron, copper, aluminium and nickel-cathodes in arcs, M. Ozawa, T. Morita, and K. Omura.

The melting-characteristics of coated electrode of iron, M. Ozawa, T. Morita, and K. Omura (16–20)

Studies on abrasion resistant materials against sand slime in a rapid current of water and their hard-face welding (Report 3), J. Ito (21–25)

Effects of powder-cutting on welding 18–8 stainless steel, K. Ishihara and M. Iwasa (26–31)

Cooling curve, microstructure and hardness in welding heat-affected zone of high tensile steel (Report 2), H. Sekiguchi, M. Inagaki, and M. Sato (32–38); (Report 3), (39–44)

On the change of quality of high-tensile steel by the water cooling operation, S. Goda, M. Ishikawa, and J. Imamura (45–48)

Welding of rail joints by the manual-arc method (Report 1), S. Morita, T. Ito, T. Yonei, and M. Fujimoto (49–53)

Przeglad Spawalnictwa (Poland), 1958, vol. 10, March

Characteristic properties of basic electrodes, J. Wegrzyn (70–75)

Submerged-arc hard-surfacing of mill rolls, K. Sniegon (77–85)

Electrodes for joining and surfacing in use in the USSR, E. W. Sokolow (86–88)

PA-2 boiler damage in a fishing trawler, M. Mysliwiec (92–93)

Przeglad Spawalnictwa (Poland), 1958, vol. 10, April

Welding of a new corrosion-resisting steel with 17% Cr, 4% Ni, 7% Mn and an addition of N_2, S. Piwowar

Repairs of brass ship propellers, R. Pasierb and M. Dymczak

Some structural weldments defects as found in mild and low-alloy steels, A. Ciszewski and T. Radomski

Schweissen und Schneiden (Germany) 1958, vol. 10, April

The load-carrying capacity of silver brazed joints for thin-walled steel tubes, Helmut Koch and K. L. Pot[illegible] (114–119)

The influence of welding current on the economy and quality of arc-welded butt welds, C. Stieler (119–125)

The influence of the welding process on discolouring during anodising of welded joints in aluminium and aluminium alloys. (125–131)

Supersonic testing of welds, W. H. Papke (131–135)

The Welder, 1958, vol. 27, January to March

Welding applications at Derby C. & W. Works, Pt. 1, A. E. Bates (2–10)

The plastic theory of structures, Pt. 1, T. M. Charlton (11–15)

A guide to nuclear power, Pt. 2 – **Nuclear reactors,** W. D. Biggs (16–20)

A new electrode for pipe welding (21–22)

Welding Engineer (U.S.A.), 1958, vol. 43, April

Knurling becomes a design criterion, W. L. Hughes and L. E. Mills (37)

A wine tanker with a "stainless" reputation for quality, Philip Ferry (38–39)

Spot welding aids in solving aircraft weight problems, Bruce Mitchell (40)

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Welded yawl cops cups, F. W. Foerste (42–44)

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Maintenance saving for the railroads (51)

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Self-imposed welding standards (54, 56, 59)

New welding method acclaimed by British, William A. Heath (62)

Welding heavy steel, Howard E. Jackson (65–66)

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Slide rule for automatic welding, A. J. Rosenberg (91, 93)

Melting points of reactor materials (97)

New graphite backing rings hold a solution, H. C. Phelps (108)

Super shovel hefts tons of earth in a quest for coal, Tom Learmont (116, 118–120, 122–124)

Welding Journal (U.S.A.), 1958, vol. 37, April

Design and fabrication by welding of the Carquinez Strait Bridge, Leonard C. Hollister (309–319)

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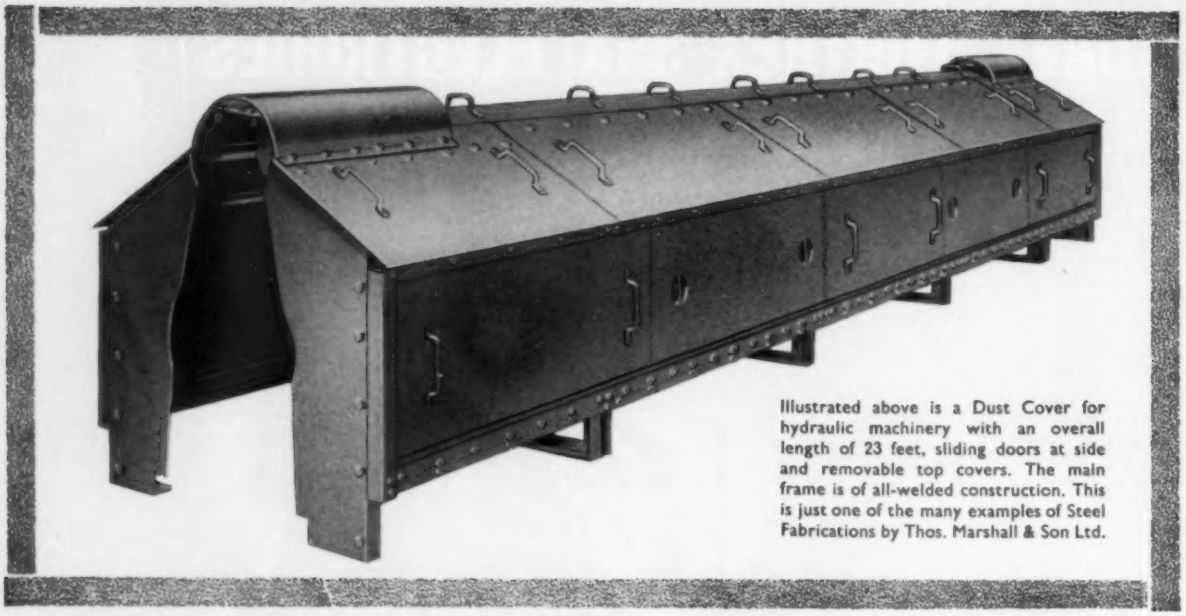

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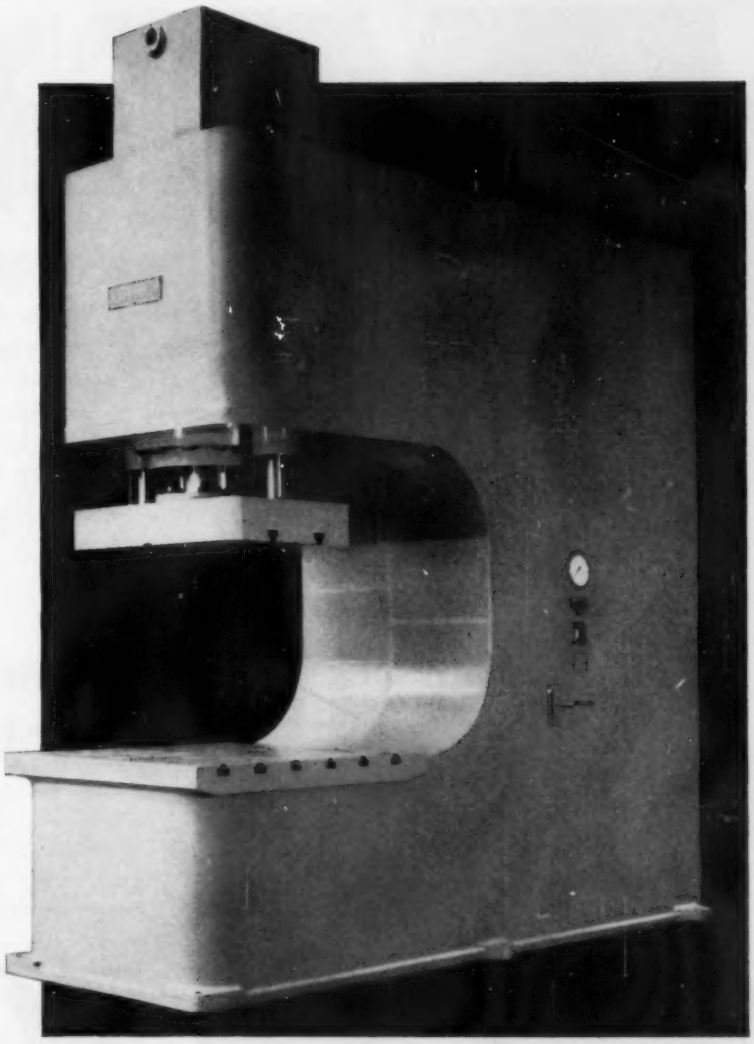

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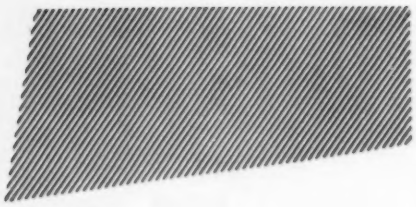

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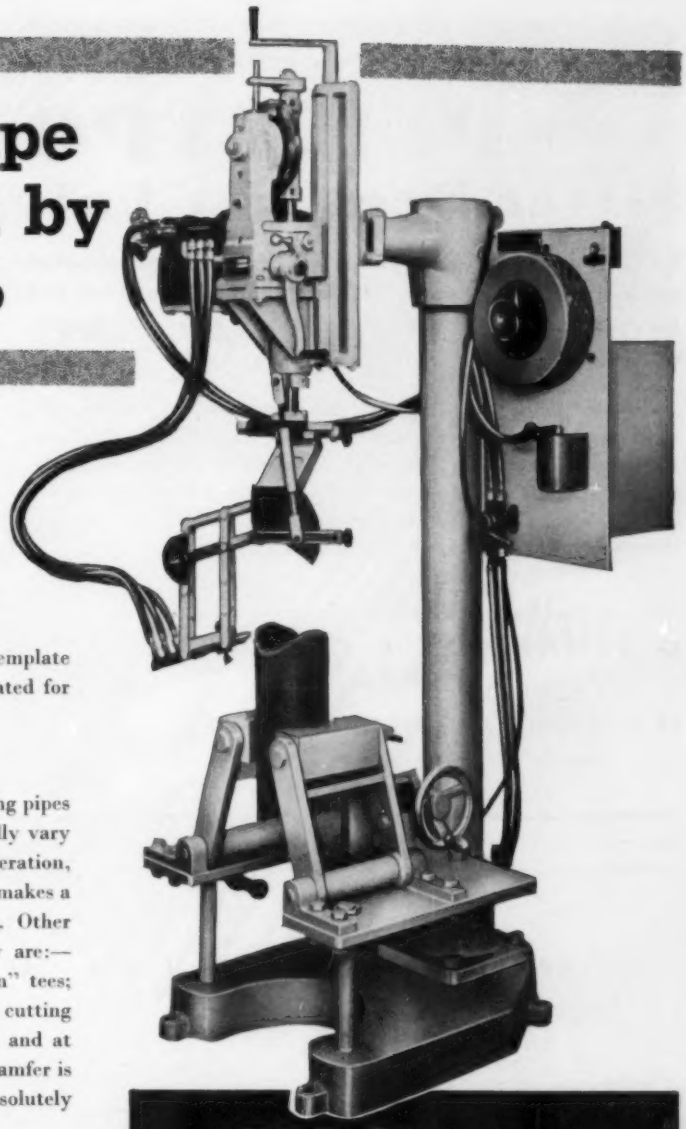

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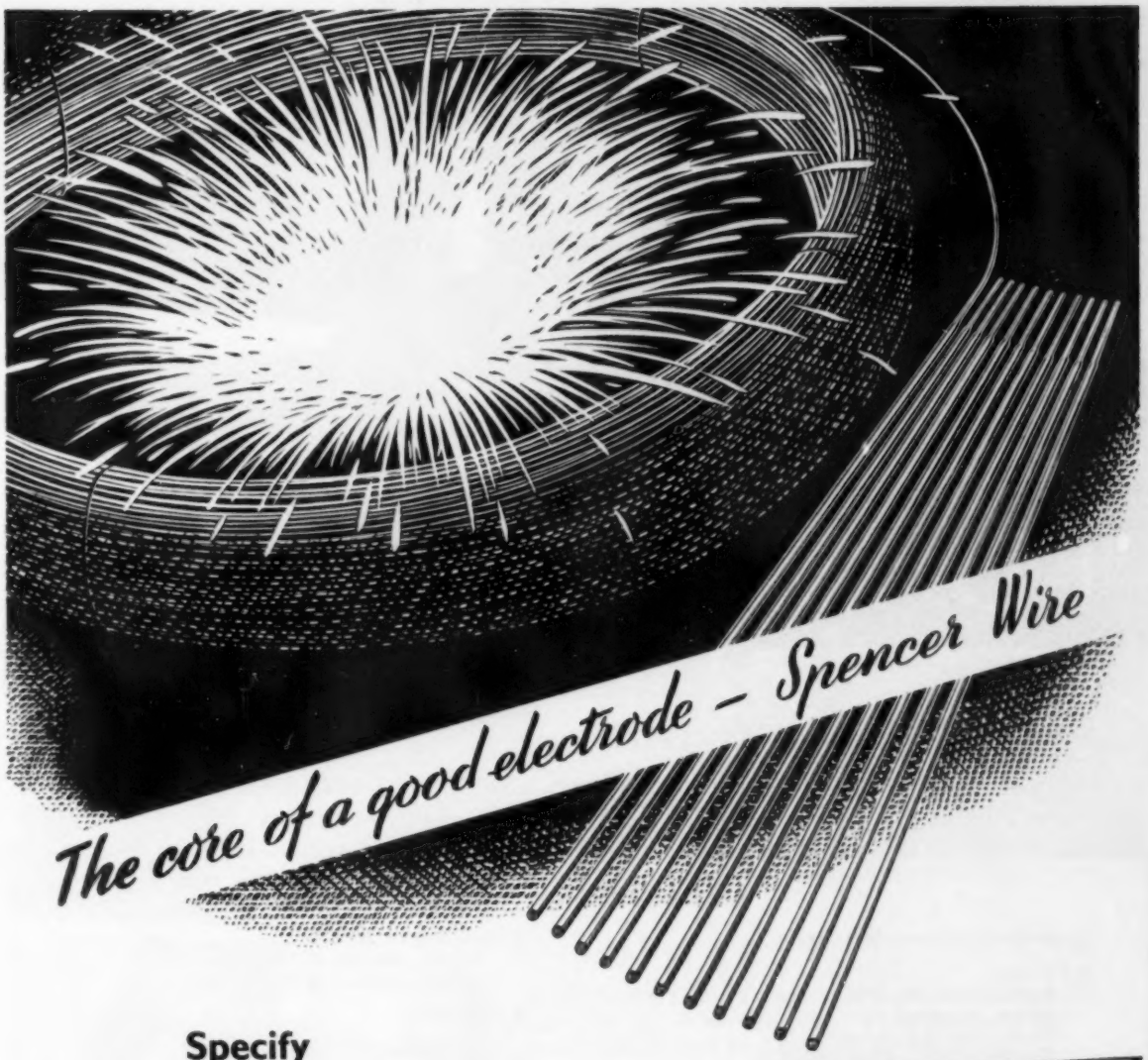

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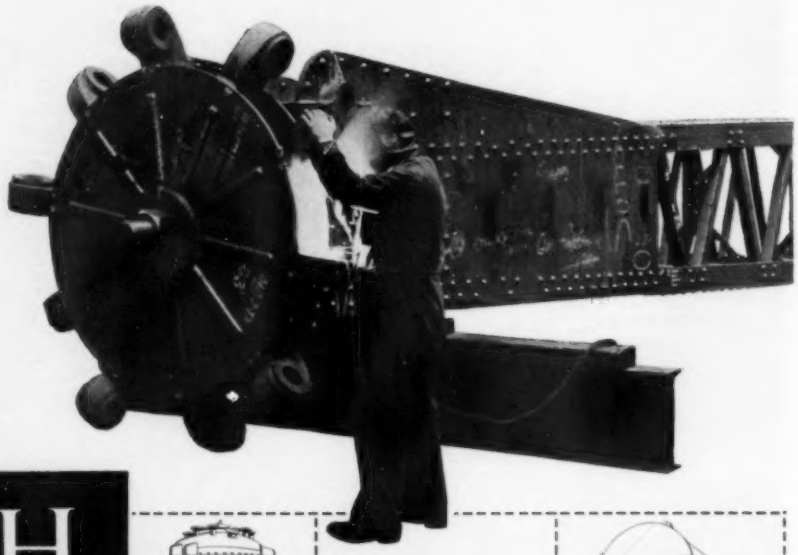

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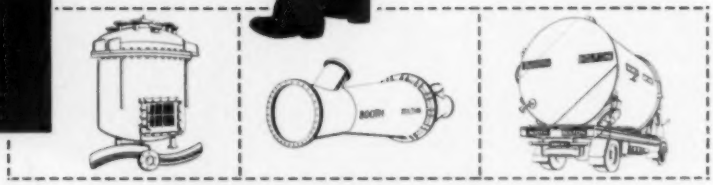

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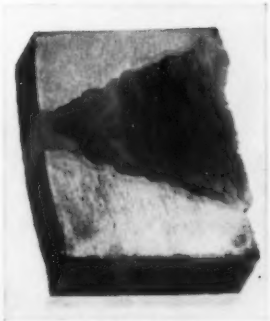

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